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[621 .33 (01 (.45)]

Electric traction using three-phase alternating current at industrial frequency,

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Fig. 1, p. 565.

1. *Foreword.* — The first enquiry into the use of electricity for traction purposes on the Italian railways was made in 1897, when the Government of the day nominated a Commission to consider the question, both technically and commercially, of electrifying the railways, and to select the best system to be used.

As a result of work done by the Commission it was decided to make three series of tests : one with accumulator locomotives on the lines between Milan and Monza and Bologna and San Felice, another with continuous current and third rail on the line between Milan and Varese; and the third with three-phase alternating current with overhead lines on the Milan-Sondrio-Lecco line (Valtelina Railway).

The experiment with accumulator locomotives was soon abandoned, but the operation of the Varese and Valtelina lines electrically has been continued with success.

For subsequent electrifications a choice had to be made between the two systems which had been tested, continuous and three-phase current. It will be observed that tests were not made with single phase current, tested and adopted in other countries.

Three-phase current was finally decided upon, and ever since that time all lines electrified in Italy to a total length of about 1 000 km. (620 miles) have followed the arrangement used on the Valtelina lines.

In other countries, on the other hand, continuous current (France, England and America) and single phase alternating current (Switzerland, Germany, Austria and America) have been widely used. The three-phase system has remained peculiar to Italy, and thereby has come to be called the « Italian » system.

As a result of the discussions and numerous criticisms that have taken place on the choice of the system of traction current to be adopted, and in view of the

invariable use of other systems elsewhere, the question of reconsidering the system adopted has again arisen in Italy. Two questions had to be considered : for subsequent electrifications should another system be selected, or if the three-phase be retained, can it be used in another and simpler and cheaper way? With regard to the first question, we have already expressed our opinion [1]. We will therefore consider the second, more especially as a good opportunity now occurs through the decision of the Italian Railways to electrify the line from Rome to Tivoli, using three-phase alternating current at the industrial frequency with characteristics very different from those so far in use. For working this line, the Breda Company had built specially designed locomotives, one of which was exhibited at the Milan Commercial Fair. Much of the data necessary for a consideration of the question is therefore available.

2. *Three-phase traction at low frequency.* — Three-phase alternating current for traction in Italy has the following characteristics : tension on the trolley : 3 600 volts; frequency : 16.7 periods per second.

3 600 volts was adopted so that the motors could use the line current : it is known that for contructional and operating reasons, a tension exceeding 4 000 volts at the motors is not desirable. The frequency of 16.7 was chosen so as to get locomotive speeds equal to the usual train speeds with normal wheel sizes, without introducing gears.

If :

n be the frequency of the current in periods per second,

$2p$ the number of poles of the motors,

V the speed to be attained by the train in kilometres per hour,

the diameter D of the wheels will be given by :

$$D = \frac{1}{3.6}\frac{Vp}{\pi n} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

when the motors work in parallel.

When $n = 16.7$, $2p = 6$, $V = 90$ km. per hour,

$$D = 1.43 \text{ m.}$$

This size is one used with both steam and continuous current locomotives.

Three-phase current for industrial purposes is generated at high tension and at 50 periods.

The following equipment is required to get the desired tension and frequency at the trolley line : generating stations at high tension and 50 periods, main distributing lines at high tension to the sub-stations ; sub-stations with static transformers to reduce the voltage to about 4 000 volts ; converters to give current at 16.7 periods (motor alternators or rotary converters) ; feeder lines from the sub-station to the locomotives. This equipment naturally causes a loss of output. With the above characteristics for the current in the distributing lines, the following are average values for the efficiency :

Main lines 95 to 98 %; sub-stations with rotary converters 80 to 85 %; contact lines 90 to 95 %. The efficiency of the whole would be between 67 and 79 %. The weak spot in the system is the conversion of the current : if the frequency had not to be reduced, static sub-stations could be used with an efficiency of between 95 and 98 % instead of 80 to 85 %, as stated above.

(1) See Corini : *Tipi e sistemi di trazione* (Types and systems of traction) (*Rivista dei Trasporti*, 1920).

To sum up, it can be said that with three-phase current at low frequency the equipment and sub-stations are very like those used with continuous current. In order to avoid converting the current or, in other words, to convert the sub-stations into simple sub-stations with static transformers, the use of current at the industrial frequency by the locomotives was thought of.

3. *Characteristics of the use of three-phase current at the industrial frequency.* In order to see if it is possible and useful to use current at 50 periods, it will be as well to see the effects of the higher frequency on the trolley line and on the locomotives

a) *Effect of the higher frequency on the trolley line.* — The overhead lines and the rails are as shewn in figure 1.

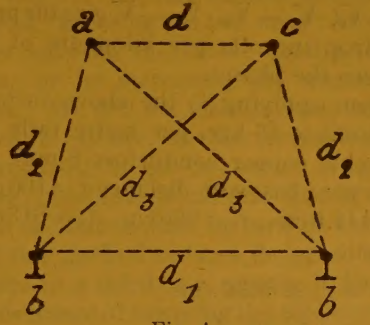

Fig. 1.

If I_a, I_b, I_c are the vectors of magnitude and phase of the intensity of the current at the different phases *a*, *b* and *c*, the drop of inductive pressure for each conductor will be given by the following vector equations :

$$\left.\begin{aligned}
\overline{V'_b} &= \frac{2\pi n}{10^4}\Big[(6.25 + \frac{n}{11.2} - 2.3\log r_r - 2.3\log d_1)\overline{I_b} - \\
&\quad - 2.3(\log d_3 + \log d_2)\overline{I_a} - 2.3(\log d_2 + \log d_3)\overline{I_c}\Big] \\
\overline{V'_a} &= \frac{2\pi n}{10^4}\Big[(0.5 - 4.6\log r_a)\overline{I^a} - \frac{4.6}{2}(\log d_2 + \log d_3)\overline{I_b} - 4.6\log d\cdot\overline{I_c}\Big] \\
\overline{V'_c} &= \frac{2\pi n}{10^4}\Big[(0.5 - 4.6\log r_a)\overline{I_c} - \frac{4.6}{2}(\log d_2 + \log d_3)\overline{I_b} - 4.6\log d\cdot\overline{I_a}\Big]
\end{aligned}\right\} \quad (2)$$

in which d, d_1, d_2, d_3 have the meaning given in figure 1, r_a is the radius of the line wire, r_r the mean radius of the rail. The units are the centimetre, second, ampere, volt; log is the vulgar logarithm (to base 10).

The pressure drop in volts is given by

$$\overline{V''_a} = R_a \cdot \overline{I_a}$$
$$\overline{V''_b} = R_b \cdot \overline{I_b}$$
$$\overline{V''_c} = R_c \cdot \overline{I_c}$$

The total pressure drop for each phase is given by the following vectorial equations :

$$\overline{V_a} = \overline{V'_a} + \overline{V''_a}$$
$$\overline{V_b} = \overline{V'_b} + \overline{V''_b}$$
$$\overline{V_c} = \overline{V'_c} + \overline{V''_c}$$

If the frequency changes from n to $n' = 3n$, for example, the inductive drops $\overline{V'_a}$, $\overline{V'_b}$, $\overline{V'_c}$ are multiplied by 3 and the total drop in pressure $\overline{V_a}$, $\overline{V_b}$, $\overline{V_c}$ increases (without being three times greater); the difference between the current and the voltage at the sub-station increases : in other words, the power factor drops.

The drop in pressure along each wire being known, the vector differences $\overline{V_a} - \overline{V_b}$, $\overline{V_c} - \overline{V_b}$, $\overline{V_a} - \overline{V_c}$ give the pressure drop in volts per kilometre of line between the phases.

When applying (1) the above vectorial equations to 45 kgr. per metre rails and to double copper conductors 8 mm. diameter per phase with distance $d = 100$ cm., $d_1 = 144.5$ cm., $d_2 = 600$ cm, $d_3 = 613$ cm., we get :

$r^a = r_c = 0.56$ cm.

$r_b = 4.27$ cm.

$R_a = R_c = 0.20$ ohm per kilometre.

$R_b = 0.05$ ohm per km., for $n = 16.7$ (skin effect taken into account).

$r_b = 0.0797$ ohm per kilometre, for $n = 50$ (skin effect taken into account).

With a frequency of 16.7 periods, the drop between phases will be as follows :

$\overline{V_{a,c}} = 0.304$ volt per kilometre and per ampere ;

$\overline{V_{a,b}} = 0.293$ volt per kilometre and per ampere ;

$\overline{V_{c,b}} = 0.293$ volt per kilometre and per ampere.

With a frequency $n' = 50$:

$\overline{V_{a,c}} = 0.773$ volt per kilometre and per ampere ;

$\overline{V_{a,b}} = 0.641$ volt per kilometre and per ampere ;

$\overline{V_{c,b}} = 0.641$ volt per kilometre and per ampere.

This shews that the drop in pressure increases in the ratio of 1 to about 2.5.

If the loss of energy through the contact line is to remain equal to that with current at a frequency of 16.7, the intensity of the current would have to be reduced in the ratio of 1 to $\frac{1}{2.5}$.

If the reduction in the power factor be ignored, when making broad approximations, for the trolley line to carry the same energy, the pressure in the trolley line has to be increased in the ratio of 1 to 2.5. In other words, if the adoption of the industrial frequency is not to result in lower efficiency in the trolley line, the feed tension should be raised from 3 600 volts to $3\,600 \times 2.5 = 9\,000$ volts ; and if the reduction in the power factor were taken into account, the conclusion is come to that the pressure should be increased to about 10 000 volts.

a) *Effect upon the locomotives.* — Formula (1) applied to the case where

$2p = 6$,

V = 90 km. an hour,

but with

$n = 50$,

gives :

D = 0.48 m.

The locomotive wheels would have to be 48 cm (1 ft. 6 7/8 in.) diameter, which is quite out of the question with the usual method of construction of railway rolling stock.

The results of increasing the frequency, so far as the rolling stock is concerned, are as follows : need to supply the locomotive with current at the pressure of 10 000 volts : necessity to use suitable means to increase the power factor at the trolley line : obligation to adopt suitable gears to reduce the angular velocity of the wheels.

To meet these requirements would result in the use of apparatus which would

(1) See Verole : *La grande trazione elettrica* (Main line electric traction). Hoepli, editor.

make the construction of the locomotive more complicated.

With regard to the first condition, it should be noted that the asynchronous motor can be fed with current at not more than 4 000 volts. It would therefore be necessary to install on the locomotive static transformers to reduce the pressure of 10 000 volts to a suitable pressure for the motor. Seeing that a transformer has to be provided, it would be better to lower the pressure to about 1 000 volts, which is the most suitable voltage for the type of motor in question. It has been noted that with 10 000 volts the most important of the losses due to the higher frequency have been made good.

It would be possible to take advantage of the transformer on the locomotive to increase the line pressure above 10 000 volts, and thereby not only neutralise the whole of the losses due to the increased frequency, but make some saving, and be able to place the sub-stations farther apart. There would, however, be the danger of short circuits between the overhead lines near points in stations where the wires come to within 10 cm. (4 inches) of one another. A voltage exceeding 10 000 volts cannot therefore be used.

The second condition mentioned above involves the installation on the locomotive of a rotary machine, the stator forming the secondary of the transformer, and the rotor corresponding to the inductor of an alternator excited by continuous current from a dynamo keyed to the motor shaft. This rotary machine has the same effect on the circuit as a synchronous motor : a synchronous motor can run with current behind, in phase or in advance in relation to the electromotive force; in this last case, it produces the same effect as a condenser, that is to say, it carries a negative reactance sufficient to counterbalance the positive reactance of the trolley line.

The third condition, that of reducing the angular velocity of the locomotive wheels, can be met in two ways : by using gears between the motor shaft and the axles, or by increasing the number of poles. We will not mention coupling the motor in cascade, as this arrangement is always used to get two series of speeds. There could also be no question of using three or four motors in turn in cascade, as if this method reduces the speed of the motors to a third or a quarter it has the disadvantage of lowering the efficiency and working of the motor below an acceptable figure.

The two expedients mentioned above remain. The use of gears has been much opposed until recently, especially for high powered machines. The construction of gears in nickel steel, and the use of flexible gears in the drive has made their use more practicable. There is, however, some loss of efficiency owing to friction when they are used.

If a large number of poles are employed, the power factor falls off seriously.

To resume what has been said above, it can be stated that the results of adopting the industrial frequency will be the following :

1. Feeder lines without change. Efficiency between 95 and 98 %;

2. Rotary sub-stations replaced by simple sub-stations, with static transformers with an efficiency of between 95 and 98 %;

3. Trolley line with higher pressure, say, 10 000 volts; loss unchanged, and consequently an efficiency between 90 and 95 %, As corollary of the higher trolley voltage, increase in first cost of the insulators and greater care needed in erection ;

4. Use of a transformer on the locomo-

tive with a resulting loss of efficiency. Efficiency of this transformer between 95 and 98 %;

5. Use of gears with an efficiency of 95 to 98 % or a greater number of poles with corresponding loss, rather greater, owing to the lower power factor;

6. Apparatus used to increase to 1 the power factor of the line. Taking into account the energy absorbed by apparatus of this kind, it can be said that its use consists in eliminating the loss represented by the falling off of the power factor of the line owing to the higher frequency.

The locomotive meeting these requirements and fitted with lighter motors has about the same weight as low frequency machines. It is much more complicated and its cost higher, the increase varying from 10 to 20 %.

The overall efficiency, with the arrangements adopted, will be between 74 and 82 %, whereas with the low frequency it was from 67 to 79 %. In these values the efficiency of the motors is not included. Against this, the first cost of the trolley line as of the locomotive is higher.

If a conclusion has to be drawn from the preceding considerations, it is that the use of the industrial frequency simplifies the transformer sub-stations, but complicates the insulation of the trolley line and the construction of the locomotive. It gives a better overall efficiency, but the cost of the construction of the locomotive and the supply of energy thereto is greater.

The advantages exceed the disadvantages when the number of trains, although large enough to justify electrification, is limited; on the other hand, the disadvantages outweigh the advantages if the traffic is heavy.

[625 .14 (01]

American tests on railway track,

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Figs. 1 to 21, pp. 574 to 593.

I. — Introduction.

A summary of tests carried out in America during the last few years by a Committee of Engineers will be given by the author in a series of articles. The tests were published in the *Proceedings of the American Society of Civil Engineers* and in the *Bulletin of the American Railway Engineering Association.*

The first set of tests, as summarised below, from the January 1918 *Proceedings* was due to the initiative of the above two societies who formed a Committee *on Stresses in Track* to investigate the stresses and strains in railway tracks.

The importance of the undertaking has been recognised, not only by the various societies of Engineers, but also by the Railway Companies, and by the learned institutions.

The Illinois Central Railroad and the Delaware, Lackawanna & Western Railroad allocated sections of line, with the test locomotives and staff necessary, to the Committee, Messrs. Moore, professor in engineering materials, and Westergaard, instructor in theoretical and applied mechanics, at the University of Illinois, lent their services to the Committee.

The members of the Committee who signed the first report were Messrs. Talbot (President), Baldwin, Bremner, Brunner, Burton, Churchill, Cushing, Hunt, Kittredge, Labach, Larsson, Ray, Reichmann, Safford, Turneaure, and Willoughby.

The work undertaken and published in four long reports is the most important contribution to the study of the track since the beginning of railways. The Americans have neither neglected nor diminished the importance of the theoretical side of the matter in these reports. The comparison between the results of tests and the theoretical deductions was found of value.

II. — Theoretical analysis.

The rail for the purposes of calculation, should be considered as a continuous beam of regular section on an indefinite number of elastic supports. If Winkler's theory be admitted, the reactions at the supports will be proportional to the deflections and the constant coefficient of proportion is the *co-efficient of reaction of the sleepers.* This co-efficient becomes the *co-efficient of ballast* when the bearing of the sleeper on the ballast is in question.

The reactions of the substructure on the rail are therefore isolated forces acting at equal distances apart due to the equal spacing of the sleepers. The calculation of the rail, in accordance with

this theory, is difficult. The author of this note in his *Note on the calculation of rails* (1) has laid down the proper method of working out the two classic cases, a load on a sleeper, and a load half way between two sleepers, and has shewn how it can be used.

The American Committee think the rail may be considered as subjected to continuous reaction in accordance with Winkler's theory of proportionality to the deflections.

This is equivalent to taking the rail as laid on continuous longitudinal bearers instead of a number of sleepers.

If u is the constant co-efficient of reaction,

y the deflection at the point in question,

p the unit reaction will be

$$p = uy.$$

The fundamental differential equation is

$$\varepsilon \frac{d^4y}{dx^4} = uy \quad \text{or} \quad \varepsilon = EI,$$

where I is the moment of inertia of the rail.

If the rail receive a single load P, the point of application being at the origin of the ordinates, the solution of the equation will be

$$y = -\frac{P}{\sqrt[4]{64EIu^3}} e^{-x\sqrt[4]{\frac{u}{4EI}}} \cos x \sqrt[4]{\frac{u}{4EI}} + \sin x \sqrt[4]{\frac{u}{4EI}}$$

and

$$M = \varepsilon \frac{d^2y}{dx^2}$$

$$M = P \sqrt[4]{\frac{EI}{64u}} e^{-x\sqrt[4]{\frac{u}{4EI}}} \left(\cos x \sqrt[4]{\frac{u}{4EI}} - \sin x \sqrt[4]{\frac{u}{4EI}} \right).$$

When

$$x = 0, \quad M \max = M_0 = P \sqrt[4]{\frac{EI}{64u}}.$$

The equation for M shews that $M = 0$ when

$$x_1 = \frac{\pi}{4} \sqrt[4]{\frac{4EI}{u}}.$$

Similarly the equation for y shews that $y = 0$ when

$$x_2 = \frac{3\pi}{4} \sqrt[4]{\frac{4EI}{u}} = 3x_1.$$

The abscissa of zero deflection will equal three times the abscissa of zero moment :

$$M_0 = 0.318 P x_1$$

and

y_0, deflection under the load $= -\dfrac{P}{\sqrt[4]{64EIu^3}}$.

u expressed in lb. per inch length of rail is the load required to give a deflection of 1 inch.

The solution of these equations is ascribed by the American Committee to Föppl : *Technische Mechanik*. It should be remembered that Zimmermann was the chief author of all early theoretical investigations in the strength of the track. In *Berechnung des Bahnoberbaues*, he laid down not only the method of calculating rails carried on longitudinal bearers (see above), but also the calcula-

(1) See *Bulletin of the Railway Congress*, August 1921 number, p. 1113.

tion of the sleepers (load on limited length), as well as the calculation of rails on spaced sleepers, making many assumptions for the sake of simplicity (Schwedler).

We took the trouble to consider and check whether the argument of the American Committee to consider the rail as of indefinite length on *continuous supports* was theoretically correct.

In the above-mentioned study (*Bulletin*, August 1921) we noted that a Dutch Engineer, Dekker, also dealt with the calculation of a rail on an indefinite number of yielding supports equally spaced.

Dekker treated the unknown quantities of the problem as exponential functions convertable into converging series. By ignoring certain terms of the higher powers of the variable, he was able to express his results in the form of continuous functions which could be simplified in any desired instance.

The method given in our study is not so elegant, but on the other hand gives exact results without it being necessary to ignore any factors.

According to Dekker,

$$\Upsilon = \frac{6EI}{Cl^3},$$

where I = moment of inertia of the rail,
C = co-efficient of reaction of the sleeper,
l = distance of sleepers centre to centre.

The equations are in Φ,

$$\Phi^4 = \frac{3}{2}\frac{1}{\Upsilon}.$$

D being the reaction of a sleeper

$$D = Cy_n.$$

If the load P is above a sleeper, the moments at the succeeding sleepers will follow the law :

$$M = \frac{Pl}{4\Phi}\, l^{-\frac{x}{l}\Phi}\left\{\left(1 - \frac{1}{6}\Phi^2\right)\cos\frac{x}{l}\Phi - \left(1 + \frac{1}{6}\Phi^2\right)\sin\frac{x}{l}\Phi\right\}.$$

Moment M_0 *under the load :*

$$M_0 = \frac{Pl}{4\Phi}\left(1 - \frac{1}{6}\Phi^2\right)$$

If the load P is at *the centre between two sleepers*, the moments on the supports follow a law analogous to that above, the co-efficient $\frac{1}{6}$ becoming $\frac{1}{12}$.

The moment *at the middle* of the *span loaded* is :

$$M = \frac{Pl}{4\Phi}\left(1 + \frac{1}{4}\Phi^2\right).$$

The reactions follow the approximative law :

$$D = \frac{1}{2}\Phi P l^{-\frac{x}{l}\Phi}\left(\cos\frac{x}{l}\Phi + \sin\frac{x}{l}\Phi\right).$$

The maximum reaction *under load* :

$$D_0 = \frac{1}{2}P\Phi.$$

Noting that $C = ul$,

$$\sqrt[4]{\frac{u}{4EI}} = \frac{\Phi}{l},$$

it will be seen that neglecting the terms in Φ^2, the results given by Dekker and those by the American note (see above) agree exactly.

In particular, as far as the zero points at M and y (D) are concerned, if the case of a load on a sleeper is considered only, M will be zero if

$$\left(1 - \frac{1}{6}\Phi^2\right)\cos\frac{x}{l}\Phi - \left(1 + \frac{1}{6}\Phi^2\right)\sin\frac{x}{l}\Phi = 0$$

that is,

$$tg\frac{x}{l}\Phi = \frac{1-\frac{1}{6}\Phi^2}{1+\frac{1}{6}\Phi^2} < 1$$

$$\frac{x_1}{l}\Phi < \frac{x}{4}$$

If $\frac{1}{6}\Phi^2$ be ignored, $x_1 = \frac{\pi l}{4\Phi}$ agreeing with x_1, found higher.

The reaction D will be nil — y zero — if in the same conditions :

$$\left(1-\frac{1}{45}\Phi^4\right)\cos\frac{x}{l}\Phi+\left(1+\frac{1}{45}\Phi^4\right)\sin\frac{x}{l}\Phi=0$$

$$tg\frac{x}{l}\Phi = -\frac{1-\frac{1}{45}\Phi^4}{1+\frac{1}{45}\Phi^4}$$

neglecting

$$\frac{1}{45}\Phi^4,\ tg\frac{x_2}{l}\Phi = -1,\ \frac{x_2}{l}\Phi = \frac{3\pi}{4}$$

$$x_2 = 3x_1$$

as found previously. Without neglecting Φ^4, but noting that most often $\Phi < 1$, $tg\frac{x_2}{l}\Phi$ will be sensibly $= 1$, taking into account the action of the sleepers $x_2 > 3x_1$.

The *maximum moment* M_0 supposing a *continuous support*

$$M_0 = \frac{Pl}{4\Phi}.$$

The results given by Dekker shew that the result is *increased*, multiplied by $\left(1+\frac{1}{4}\Phi^2\right)$ in the case of a load at the centre of the span, and *diminished*, multiplied by $\left(1-\frac{1}{6}\Phi^2\right)$ in the case of a load on a sleeper.

The simplified co-efficients of Zimmermann are in the first case (three spans and load at the centre of the middle span) :

$$\frac{8\gamma+7}{4\gamma+10}\times\frac{Pl}{4}.$$

In the second case (two spans, load at the centre support) :

$$\frac{4\gamma}{3\gamma+2}\times\frac{Pl}{4}.$$

In our note of *August 1921*, we calculated the bending moments for certain types of track of the Belgian State Railways — track with 40.65 kgr. per lineal metre (81.94 lb. per yard) rails, and co-efficients of ballast of 4 and 14 ; track with rails weighing 50 kgr. per metre run (100.79 lb. per yard) (type 100 lb. Pennsylvania).

Comparison with the results from the *above* expressions are given below.

The term of comparison is the value of the bending moment, supposing the load at the centre of a span of a rail cut off at the sleepers. Ignoring the signs, this moment is $\frac{Pl}{4}$, P being the load, l the spacing of the sleepers.

The tables include co-efficients for multiplying this value in the various hypotheses considered.

I. — Rail of 40.65 kgr. per metre run (81.94 lb. per yard).

Co-efficient of ballast 14, $\gamma = 0.7$.

Axle at the middle of a span :

Continuous support, $\frac{1}{\Phi}$	0.83
Dekker, $\frac{1}{\Phi}\left(1+\frac{1}{4}\Phi^2\right)$	1.14
Study of 1921, exact result	0.956
Result of Zimmermann	0.985

Axle on sleeper :

Continuous support, $\frac{1}{\Phi}$	0.83
Dekker, $\frac{1}{\Phi}\left(1-\frac{1}{6}\Phi^2\right)$	0.63
Study of 1921	0.608
Zimmermann	0.685

II. — Rail of 40.65 kgr. (81.94 lb. per yard).

Co-efficient of ballast 4, $\gamma = 2.1$.

Axle at a centre of a span :

Continuous support, $\frac{1}{\Phi}$	1.09
Dekker, $\frac{1}{\Phi}\left(1+\frac{1}{4}\Phi^2\right)$	1.23
Result of 1921	1.18
Zimmermann	1.29

Axle on a sleeper :

Continuous support, $\frac{1}{\Phi}$	1.09
Dekker, $\frac{1}{\Phi}\left(1-\frac{1}{6}\Phi^2\right)$	0.935
Result of 1921	0.912
Zimmermann	1.02

III. — Rail of 50 kgr. per metre run (100.79 lb. per yard).

Co-efficient of ballast 14, $\gamma = 1.2$.

Axle at the centre of a span :

Continuous support, $\frac{1}{\Phi}$	0.94
Dekker, $\frac{1}{\Phi}\left(1+\frac{1}{4}\Phi^2\right)$	1.2
Result of 1921	1.082
Zimmermann	1.12

Axle on a sleeper :

Continuous support, $\frac{1}{\Phi}$	0.94
Dekker, $\frac{1}{\Phi}\left(1-\frac{1}{6}\Phi^2\right)$	0.77
Result of 1921	0.76
Zimmermann	0.85

IV. — Rail of 50 kgr. per metre run (100.79 lb. per yard).

Co-efficient of ballast 4, $\gamma = 3.4$.

Axle at the middle of a span :

Continuous support, $\frac{1}{\Phi}$	1.23
Dekker, $\frac{1}{\Phi}\left(1+\frac{1}{4}\Phi^2\right)$	1.43
Result of 1921	1.312
Zimmermann	1.45

Axle on a sleeper :

Continuous support, $\frac{1}{\Phi}$	1.23
Dekker, $\frac{1}{\Phi}\left(1-\frac{1}{6}\Phi^2\right)$	1.1
Result of 1921	1.108
Zimmermann	1.12

An examination of these co-efficients shews that the hypothesis accepted by the American Committee gives results lower than the true ones in the case of a load applied between supports, and on the other hand too high for the case of a load on a sleeper.

The advantage of the hypothesis is in the possibility of tracing the influence lines of the moments and of examining analytically the effect of the different axles on the sleepers and between them.

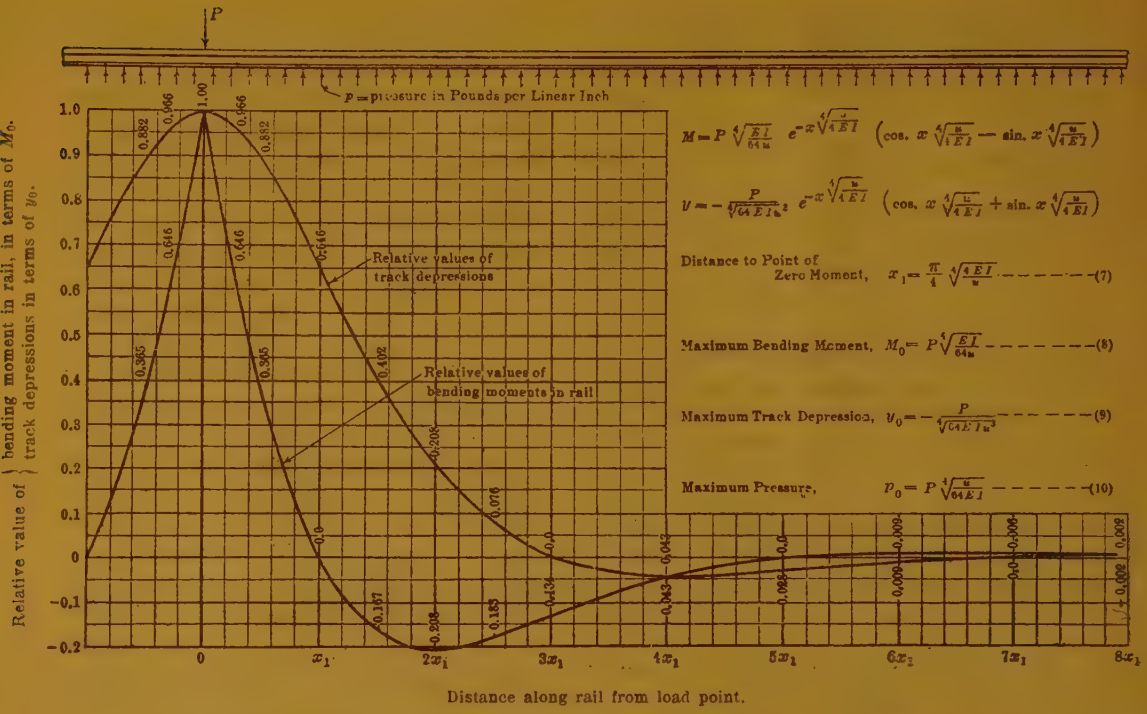

P
p = pressure in Pounds per Linear Inch
Relative values of track depressions
Relative values of bending moments in rail
Relative value of { bending moment in rail, in terms of M_0. / track depressions in terms of y_0.
Distance along rail from load point.
$M = P\sqrt[4]{\frac{EI}{64u}}\, e^{-x\sqrt[4]{\frac{u}{4EI}}} \left(\cos. x\sqrt[4]{\frac{u}{4EI}} - \sin. x\sqrt[4]{\frac{u}{4EI}}\right)$
$y = -\frac{P}{\sqrt[4]{64EIu^3}}\, e^{-x\sqrt[4]{\frac{u}{4EI}}} \left(\cos. x\sqrt[4]{\frac{u}{4EI}} + \sin. x\sqrt[4]{\frac{u}{4EI}}\right)$
Distance to Point of Zero Moment, $x_1 = \frac{\pi}{4}\sqrt[4]{\frac{4EI}{u}}$ ----------(7)
Maximum Bending Moment, $M_0 = P\sqrt[4]{\frac{EI}{64u}}$ ----------(8)
Maximum Track Depression, $y_0 = -\frac{P}{\sqrt[4]{64EIu^3}}$ ----------(9)
Maximum Pressure, $p_0 = P\sqrt[4]{\frac{u}{64EI}}$ ----------(10)

Fig. 1. — Master diagram for 1) moment developed in the rail and 2) intensity of pressure against the rail, and depression of the rail, single wheel load.

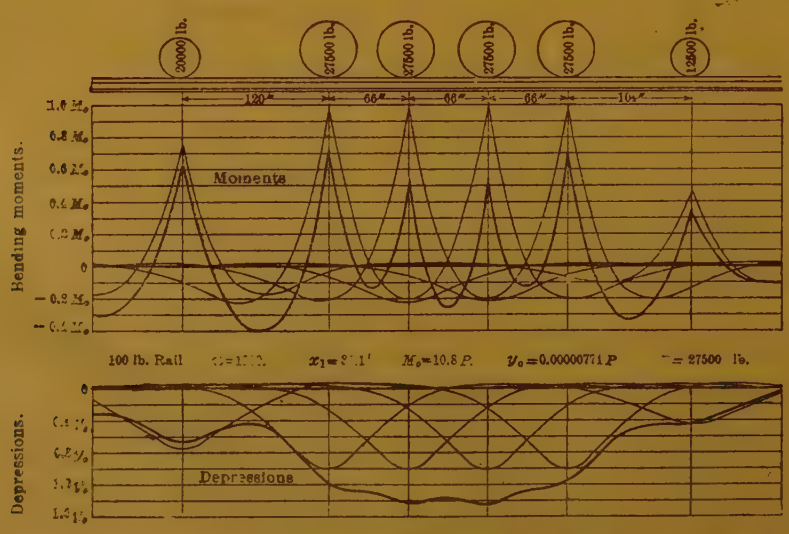


Fig. 2. — Bending moments and track depressions for *Mikado* locomotive, from analysis, 100-lb. rail.

We note also that, whereas there is almost exact agreement between the results obtained by Dekker and our figures of 1921, in the case of a *load on a sleeper* marked differences are found in the case of a load midway between sleepers. They must be ascribed to the simplifications introduced by Dekker.

The results justify the remark made in 1921 that he hypotheses of Zimmermann largely satisfy the facts, and can be used with confidence in ordinary practice.

III. — Experimental tests of the track.

When making track tests, the stresses and depressions of the rails, pressures and depressions in the ballast, and deformations of the sleepers should be measured. The measurements were made with a simple reliable apparatus rather than with too sensitive instruments.

Test sections. — A test section on the Illinois Central Railroad was on the double track main line 2 miles to the north of Champaign, Ill., over which practically only passenger trains run so that the traffic is constant.

The line is laid on an embankment, 4 to 8 feet high, of loam and clay. The first track was laid in 1854, and the second in 1900. The embankment can be considered as well compacted and dry.

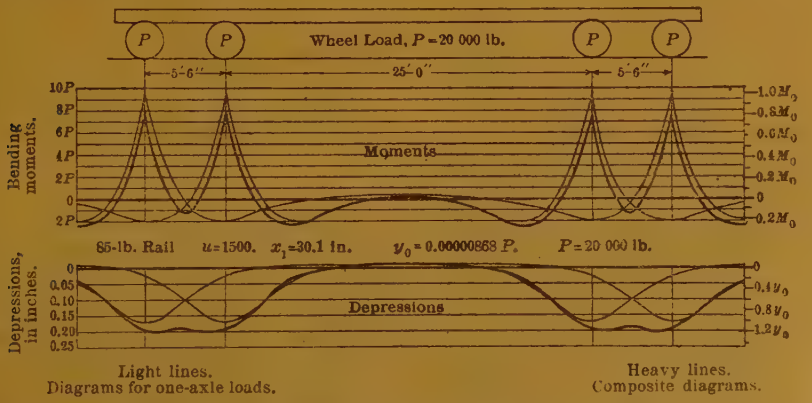


Fig. 3. — Bending moments and track depressions for loaded car, from analysis, 85-lb. rail.

The ballast consisted of broken limestone, and was about 12 inches deep under the sleepers. The rails « Am. Soc. C. E. » pattern, weigh 85 lb. per yard.

Four test sections of well marked types were prepared. The sleepers were replaced by new oak sleepers. One of the sections had 6 inches of ballast under the sleepers, a second, 12 inches and a third, 24 inches. One section had 7 × 9 inches × 8 feet sleepers, the others having 6 × 8 inches × 8 feet sleepers. Care was taken when replacing the sleepers not to disturb the ballast underneath.

Tests to measure stresses in the rails. — The first report with which we are now dealing considered the measurement of stresses in the rails and depressions of the track. Static and dynamic stresses were measured. The static tests were made with loads of rails on wagons with

bogies a considerable distance apart, and then with locomotives at slow speeds.

The dynamic tests considered especially the effects of speed without specially noting the influence of the locomotive counter-balancing (fig. 4).

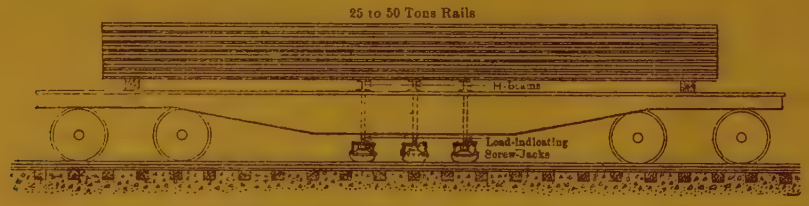


Fig. 4. — Loading apparatus for one-axle and two-axle loads.

The test locomotives on the Illinois Central Railroad were a *Mikado* (2-8-2), an *Atlantic* (4-4-2) and a *Pacific* (4-6-2).

During the tests, the locomotives were in good running order.

The maximum speed, of 35 miles per hour for the *Mikado*, and of 60 miles per hour for the others, was also used during the tests.

The test sections were run over with the regulator closed to eliminate the effect of the pull on the stresses. Care was also taken to locate the counterbalance weights in as near the same position as possible to avoid relative errors.

Other tests were also made on the Delaware, Lackawanna & Western Railroad on a section near Dover, N. J., laid with 101-lb. rails on creosoted pine wood sleepers of 7×9 inches $\times$ 8 ft. 6 in. with bearing plates and spikes. The ballast was « trap rock » 18 inches thick under sleepers above 2 feet of ashes originally used as ballast. The fill of little height, was clay mixed with boulders. The tests were made with a *Ten wheel* (4-6-0) and two *Pacific* (4-6-2), one for passenger and one for fast goods, locomotives.

Results of tests. — The published results deal exclusively with the principal conclusions drawn from the tests, ignoring accessory factors. The results are the average of a great number of observations. When it is realised that over 250 000 records of stresses were made on rails alone, it will be understood that it was necessary to deal with the essential results and averages only.

The present note only deals with the measurement of the stresses in the rails and of the depressions of the track as a whole.

Depression of the track. — The depression of the track is, as a rule, elastic, that is to say, it disappears as the load causing it ceases to act. The rigidity or flexibility of the track depend upon the cross section of the rail, its characteristics, so far as bending is concerned, the size and spacing of the sleepers, the kind and depth of the ballast, as well as on the underlying ground formation.

This review will only consider the depression of the track as a whole, without noticing the respective influence of the rails, sleepers and ballast.

As an idea, the partial depression of the different parts, caused by the passage of the driving wheels of a *Mikado* locomotive, has the following approximative values when the track is in good order : compression of the sleeper under the rail and effect of bending of the sleeper

to bring it to full bearing on the ballast, 0.05 inch; compression of 24 inches of stone ballast under the rail, 0.15 inch; compression of roadway, 0.15 inch.

The bending of the rail between the sleepers is slight; the deflection of the rail between two adjacent sleepers under the weight of the driver of the *Mikado* on 85-lb. rail was not more than 0.01 inch with sleepers spaced 22 inches. For heavier rails the deflection will of course be less.

So far as the relationship between the load and the depression is concerned, the track depression is proportional to the load for well kept track : if the track is not well tamped — old maintenance — the first part of the depression which brings the sleeper down on to its seat by taking up all play is independent of the load.

The subsequent elastic depression is proportional to the load.

Static depression of the track under one or two concentrated loads. — The sleepers are spaced 22 inches apart, and the two concentrated loads act at 66-inch centres. The diagrams given later (figs. 5 to 7) shew the results of tests with the load, or two loads, on the sleepers, or half-way between two adjacent sleepers. The diagrams shew little difference in the depression curves whether the load or loads are between or to one side of the sleepers. The deformation is a little greater when the load is to one side of a sleeper.

A marked difference is noted between sleepers recently packed and those done some time previously. New packing applies to work done within one or two weeks, with subsequent train movements.

With sleepers recently packed, the straight line for the deformations passes through the origin. The deformation is therefore proportional to the load.

This property indicates that there is a constant co-efficient of elasticity for the track. This co-efficient has a determining effect on the stresses in the rail under load.

In the case of *sleepers not recently packed,* it is noticeable that the deflections corresponding to light loads are proportionally greater that at the middle and end of the test. The line corresponding to the end of the test is straight and practically parallel to the straight line in the former case (sleepers packed). There is — as pointed out above — under the first light loads a taking up of the play between rails, sleepers and ballast, a deflection, due to poor packing which is not elastic.

The abscissa through the origin of the straight line is in this case about 0.20 inches, whereas it is barely 0.03 to 0.1 inch with properly maintained track. The distance between the load and the point of zero deformation is difficult to determine exactly because of the flatness of the curve near the points concerned. The tests also shew that the maximum depression is greater with two loads than with one.

It will also be noticed that there is no reversal of the curve with two loads for 85-lb. rails : with a less rigid rail or a wider sleeper spacing this change occurs. It should also be noted that the depressions fall off with 100 or 125-lb. rails and that the curve flattens out (fig. 8).

Stresses in the rail under separate loads. — The diagrams below shew the changes in stress in the flange of the rail under one separate load, or under two separate loads, as defined above (figs. 9 and 10).

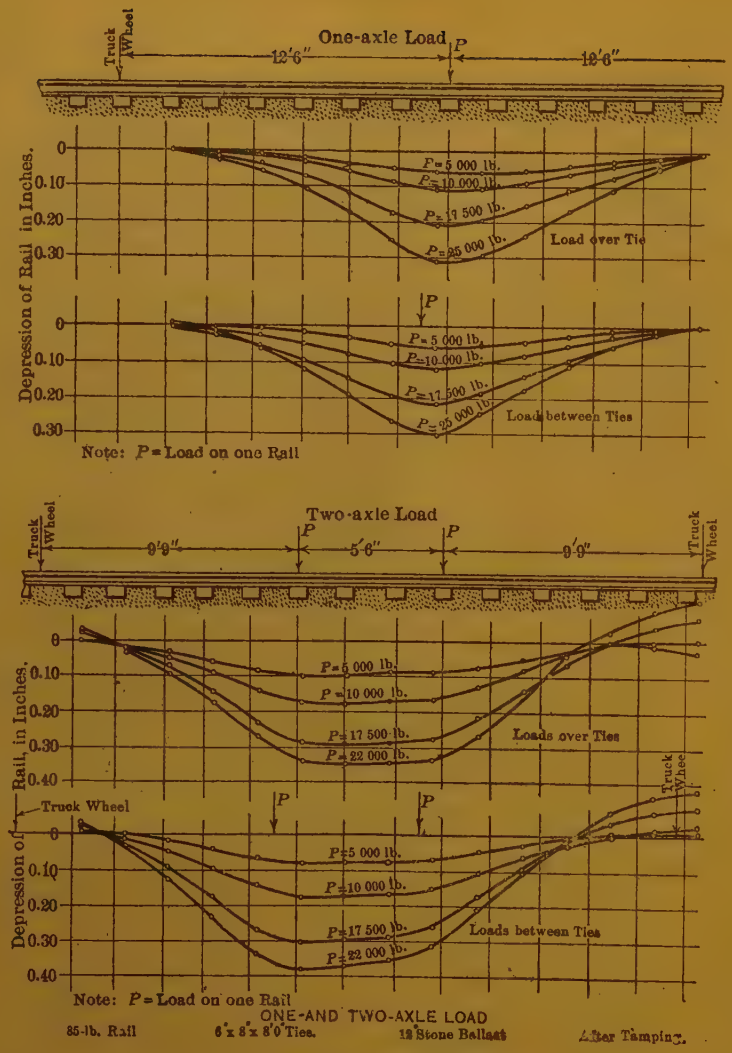


Fig. 5. — Track depression profiles.
Static-load test on Illinois Central Railroad with loading apparatus.

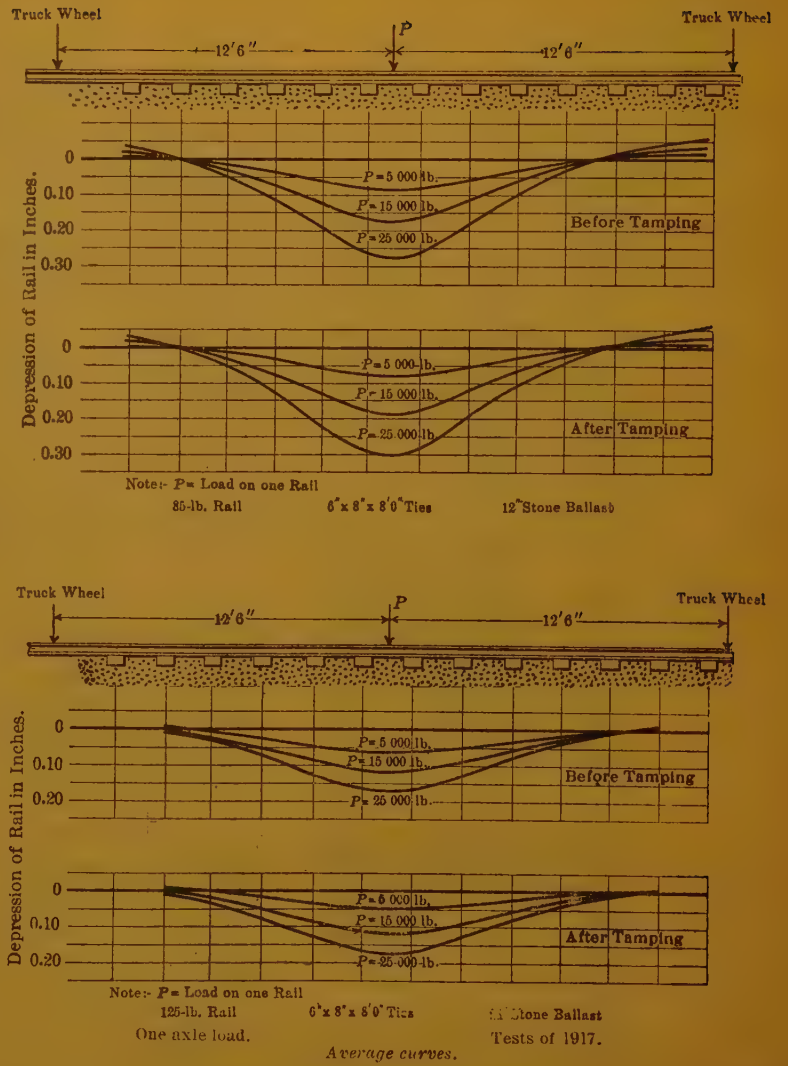


Fig. 6. — Track depression profiles.
Static-load tests on Illinois Central Railroad with loading apparatus.

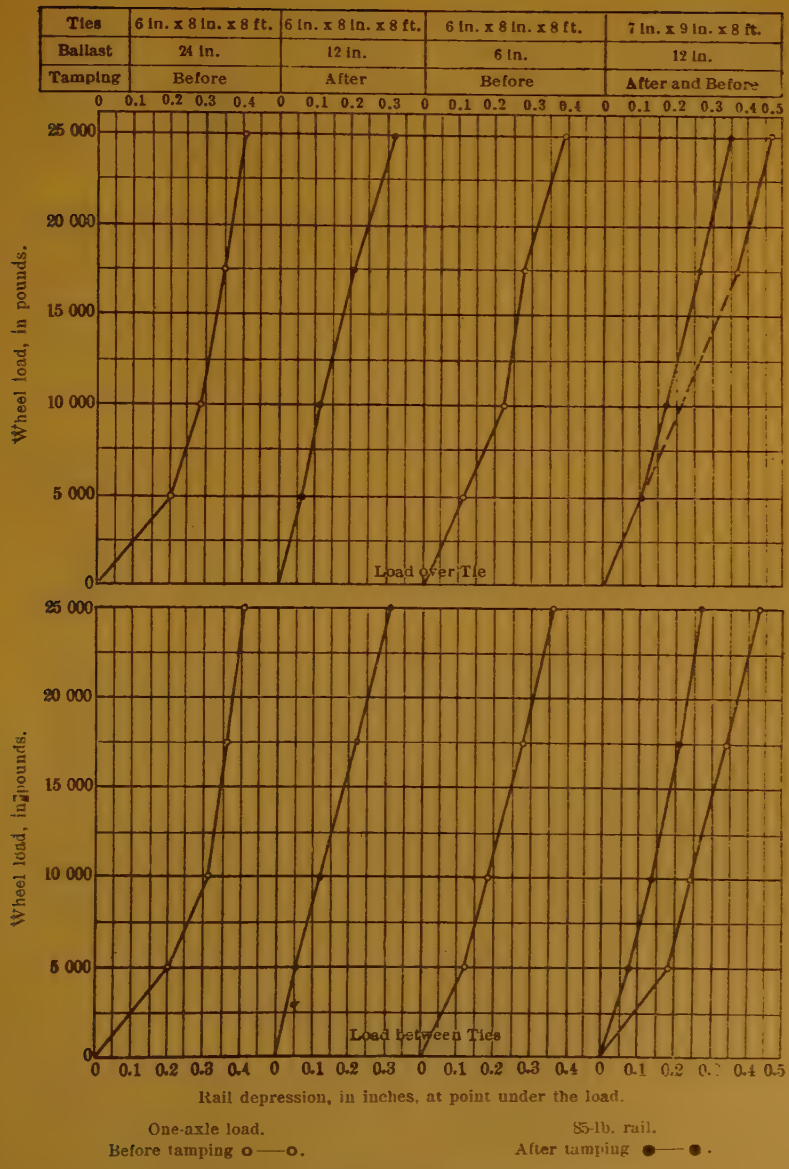


Fig. 7. — Load-depression diagrams.
Static-load test on Illinois Central Railroad with loading apparatus.

The difference in stresses is small according as the load is *on* or *between* the sleepers. The stress is usually a little higher between sleepers, although the difference is less than the difference in values obtained from different tests.

The *state of maintenance* causes greater differences in the stresses measured. These stresses are less in track newly packed than on a line in use some time.

With newly packed track, the changes in stress follow a straight linear law through the origin : the stress can be said to be proportional to the load. With old track, the points for high loads fall on a straight line which passes to the right of the origin. This line is approximately parallel to the former.

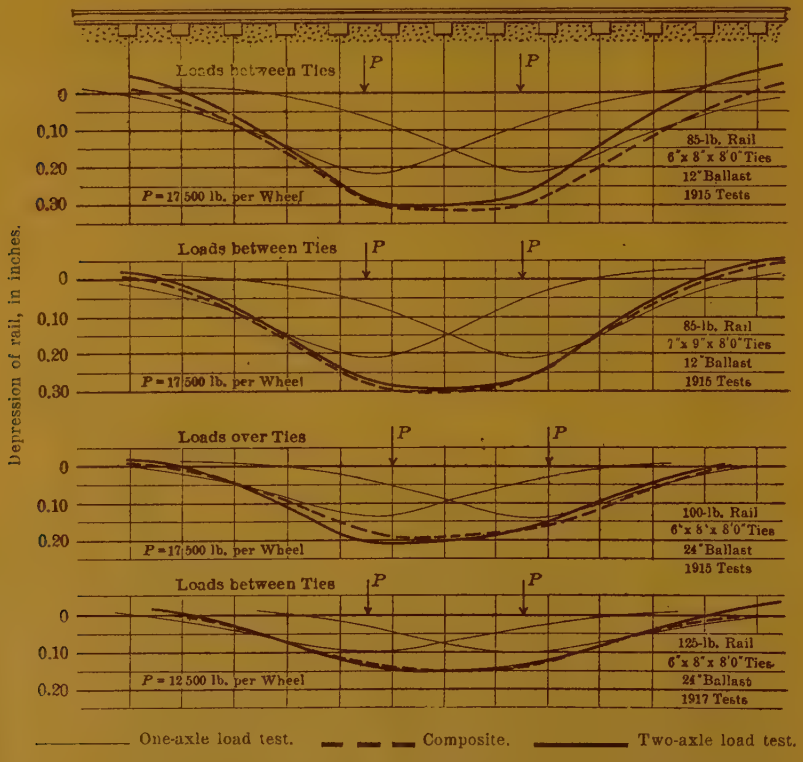
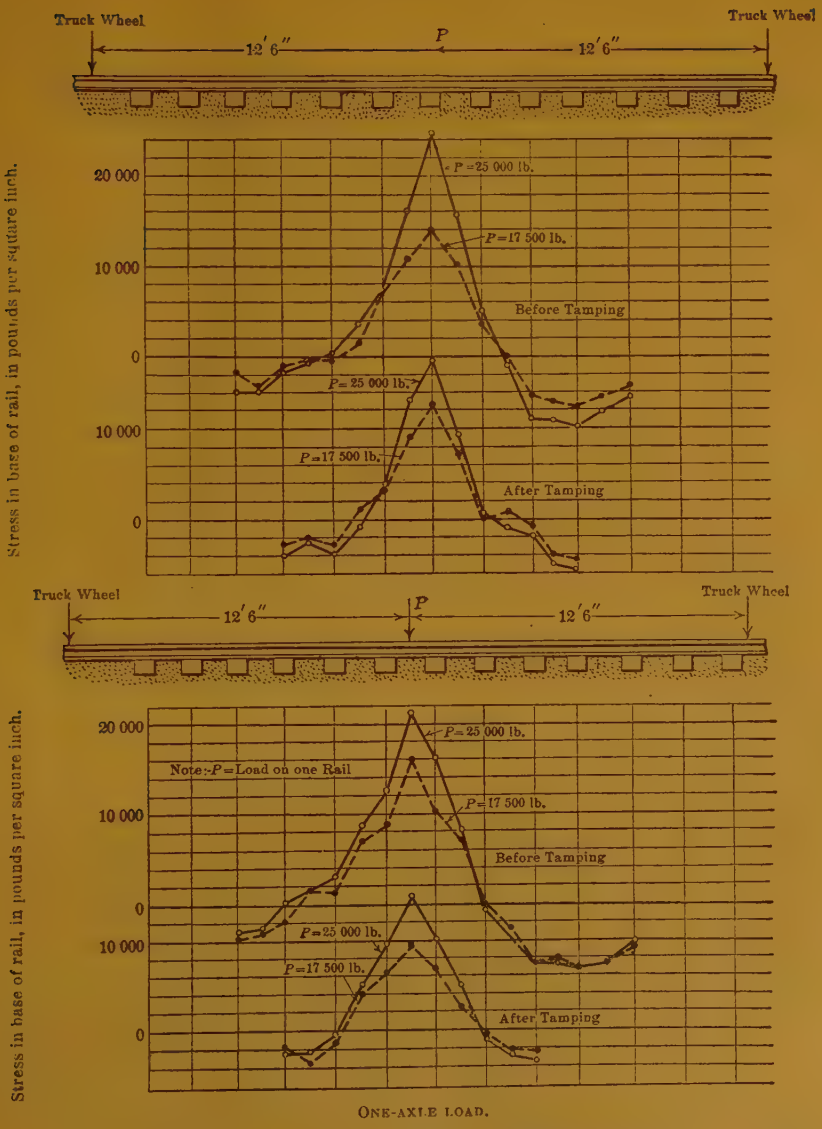


Fig. 8. — Track depression profiles from two-axle load tests, and composite profiles from one-axle load tests.

For 85-lb. rails the stress in unpacked track exceeded by about 6 000 lb. per square inch the stress in a track newly packed, no matter what the load applied or the stress expected.

The diagrams shewing the stress distribution throughout the length of the rail correspond generally to the theoretical diagram. The points of zero tension are difficult to determine from the diagrams : by approximation the distance between the point of application of the load and that of zero stress can be taken as three times the distance previously determined between the point of application of the load and the point of zero deformation.

The diagrams also shew that the stress is less under two separate loads than under one. With the spacing taken for



85-lb. rail. 7 × 9 inches × 8 feet ties. 12 inches stone ballast.

Fig. 9. — Stress distribution diagrams.
Static-load tests on Illinois Central Railroad with loading apparatus.

the loads, the second load causes a negative moment in the rail to the right of the first.

Figure 11 gives a comparison between the diagram for two loads, the diagram obtained by combining the diagrams for

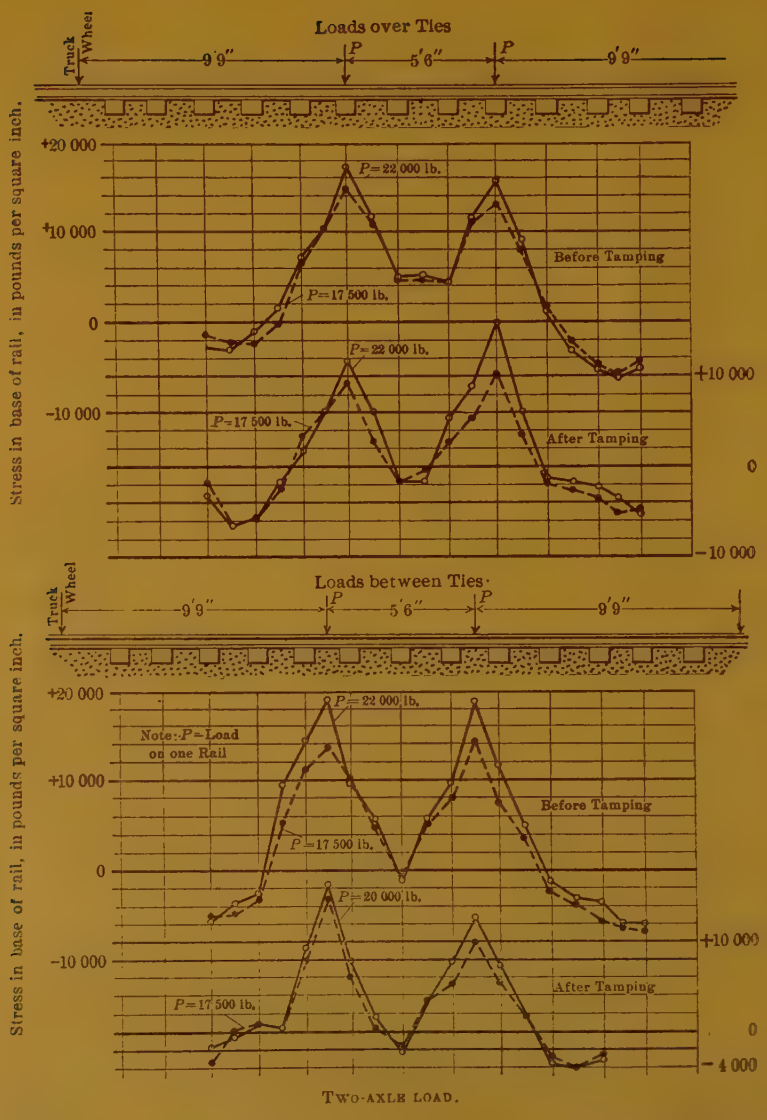


Fig. 10.— Stress distribution diagrams.
Static-load tests on Illinois Central Railroad with loading apparatus.

a single load, and the theoretical diagram.

The theoretical diagram of figure 12 shews the influence of the spacing of the forces on the law of change of the moments. The curve a is based on a distance x_1 between the force and the point of zero moment, equal to two-thirds of the distance between the forces : the

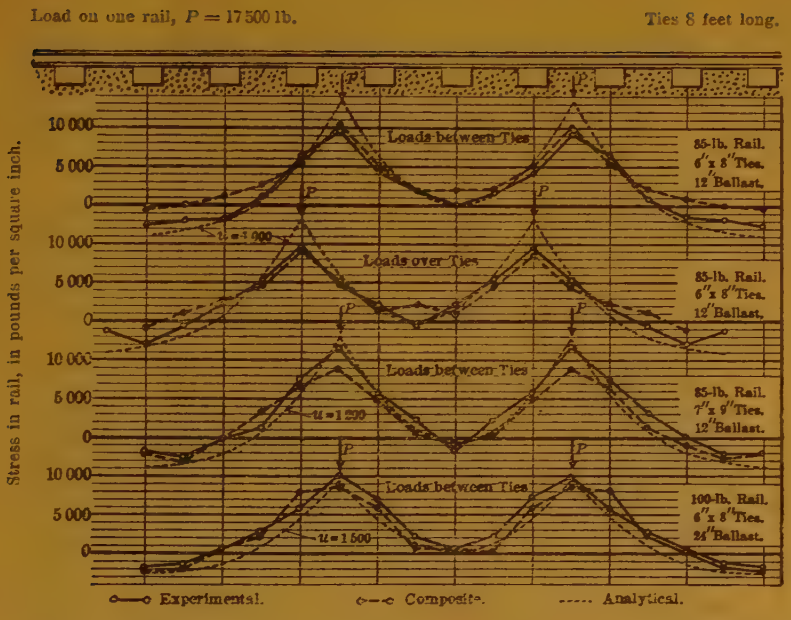


Fig. 11. — Composite stress distribution diagram for two one-axle loads from tests on Illinois Central Railroad.

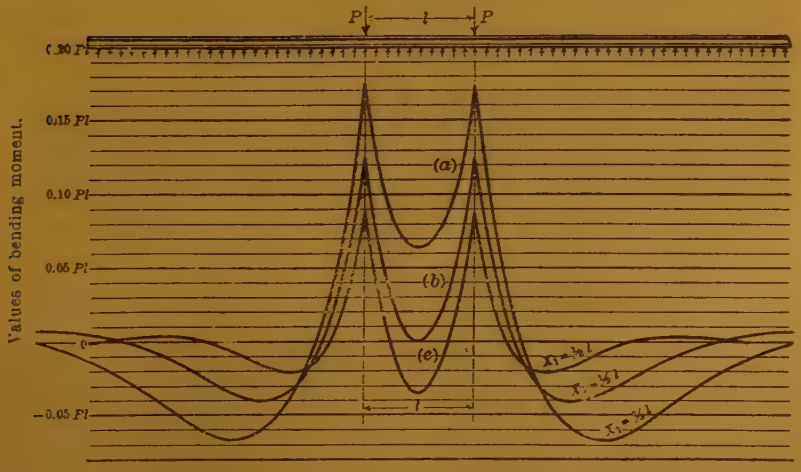


Fig. 12. — Bending moment diagrams for two-axle load, derived from analysis.

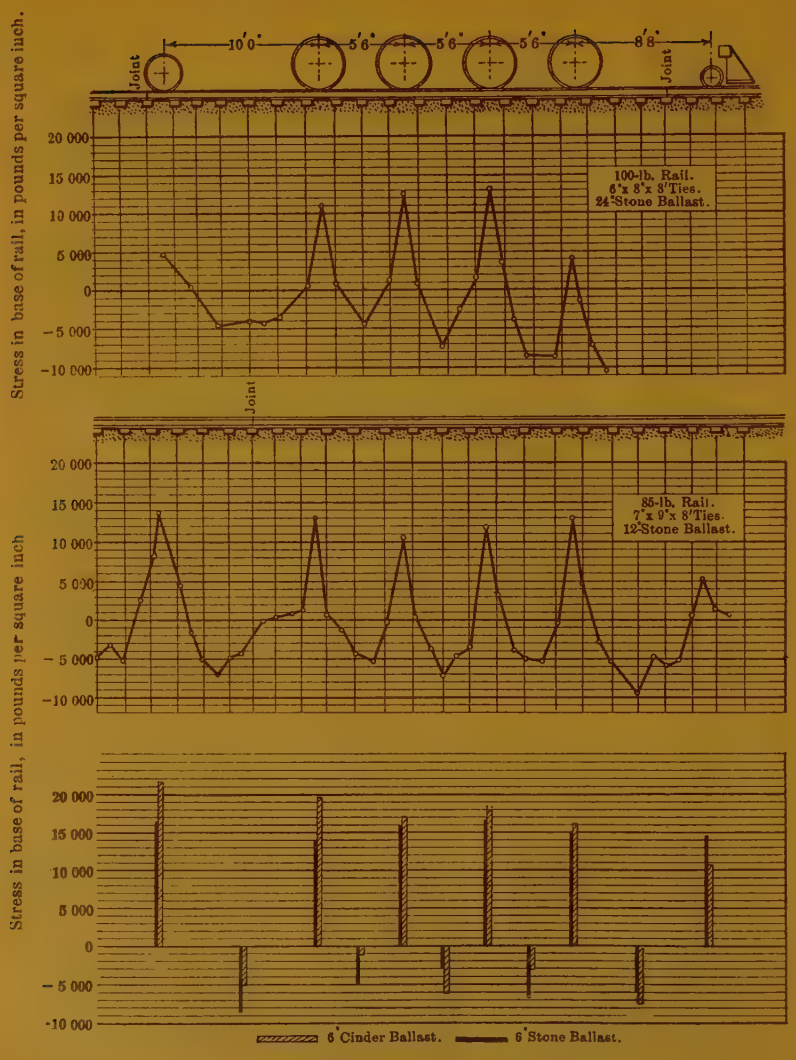


Fig. 13. — Stress distribution diagrams.
Static-load tests on Illinois Central Railroad with *Mikado* locomotive.

curve b corresponds to $x_1 =$ one half and the curve c to $x_1 =$ one third of this distance.

The true curve depends upon the distance apart of the loads, the section of the rail and the elasticity of the track.

For 85-lb. rails, the stress curve shews a negative moment between the loads — for newly packed track. The form of the curve corresponds to $x_1 = 28$ inches.

For old track 85-lb. rails, the positive moment at equal distance from the loads

is 0.25 of the moment under load, and the stress under load is greater than in the preceding case.

In newly packed track with 100-lb. rails, the diagram of stresses gives zero moment half way between the loads. The form of the diagram corresponds to a distance x_1 of 33 inches, one half of the distance between the loads.

With old tracks with 100-lb. rails, the moment at the centre is positive and equals 0.4 of the moment under load.

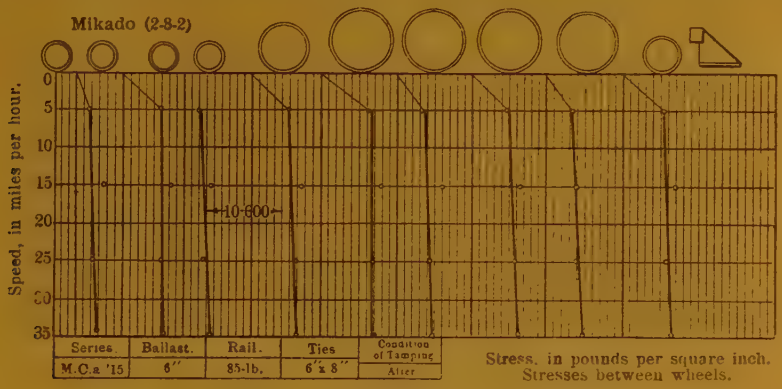


Fig. 14. — Speed-stress diagrams.
Moving-load tests on Illinois Central Railroad with *Mikado* locomotive.

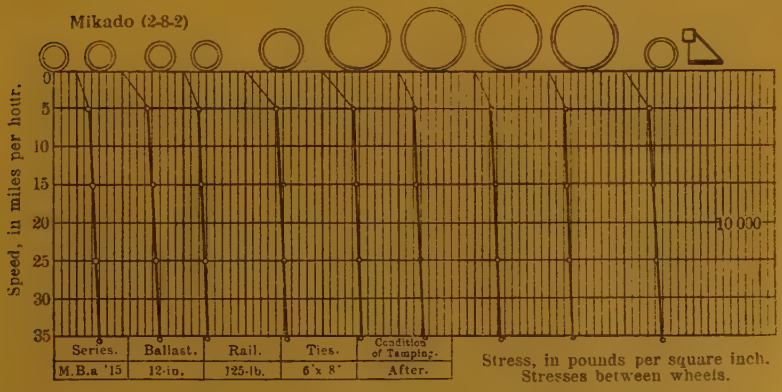


Fig. 15. — Speed-stress diagrams.
Moving-load tests on Illinois Central Railroad with *Mikado* locomotive.

Static tests under Mikado locomotives. — Figure 13 gives the static diagrams of the tests with *Mikado* locomotives on newly packed track with 85 and 100-lb. rails.

The diagram shews that the maximum stresses with positive moments occur under the wheels. Negative moments are found between the wheels. The stresses under the inner coupled wheels are usually less than under the outer, and the stress under the leading coupled wheel is a little more than under the trailing coupled wheel.

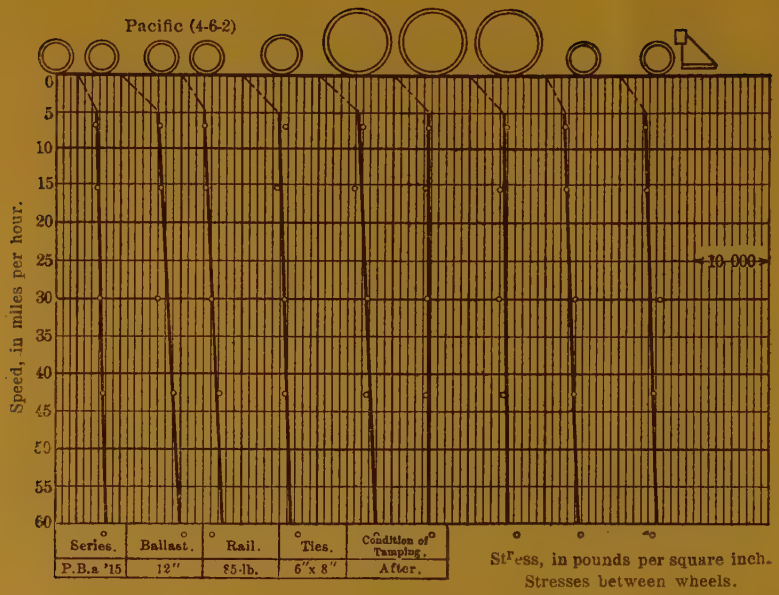


Fig. 16.

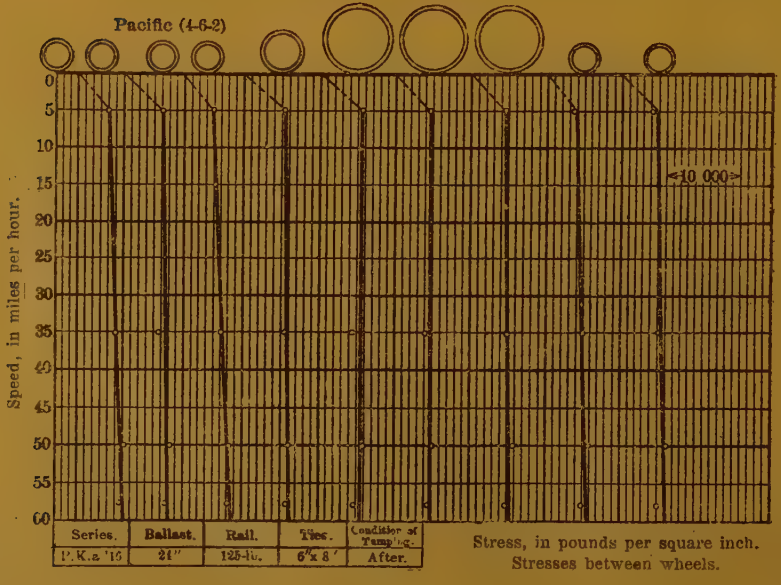


Fig. 17.

Figs. 16 et 17. — Speed-stress diagrams.
Moving-load tests on Illinois Central Railroad with *Pacific* locomotive.

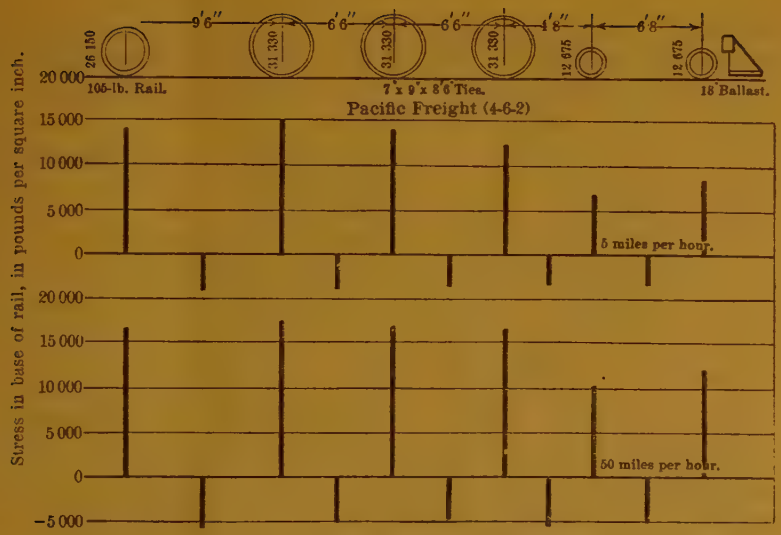


Fig. 18. — Stress distribution diagrams.
Moving-load tests on Delaware, Lackawanna & Western Railroad with *Pacific* freight locomotive.

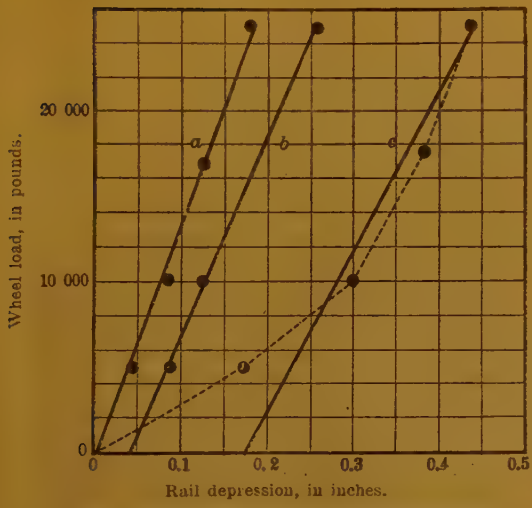


Fig. 19. — Typical load-depression diagrams.

The maximum negative moment occurs between the leading carrying wheel and the first coupled wheel. The stress is about 40 to 60 % of that under the leading coupled wheels. The stress under the trailing carrying wheel is almost as great as the stress under the outer coupled wheels, although the load on this axle is only three-quarters of the load on a coupled wheel.

The tests on track with 100-lb. rails give results a little lower, as would be expected, although the shape of the diagram is the same.

Dynamic tests. Measurement of the stresses under locomotives at speed. — In order to get comparable results with locomotives in motion, care was taken to get the counterbalance weights into the same relative position with regard to the point to be passed.

Figures 14 to 18 give a clear summary of the results of the tests.

Modulus of elasticity of the track. — This modulus refers to the rail supports, and is the pressure per unit of length of rail to depress the track one unit. This

modulus measures the vertical stiffness of the supports. It depends upon the elasticity of the sleepers themselves, the elasticity of the ballast (on its kind, thickness, etc.) and on the subsoil, and the way the pressures are transmitted to it.

This modulus can be used to indicate the quality of the track. The definition appears to imply that this quantity is a constant for any given track. Actually we have seen that the deformation is not always proportional to the load, and especially so with unpacked track. The position can be shewn by the diagram (fig. 19) for the three sets of conditions : *a*) straight line through the origin, constant modulus; *b*) straight line to the right of the origin, the case of a partial depression of a badly packed line, corresponding to the application of the sleeper to its bed; *c*) the law of variation is not perfectly linear, as an approximation a linear law corresponding to the higher values can be admitted.

The values of this modulus have been calculated by adding together the depressions of the sleepers over the length deflected. By dividing the total load of the wheels by the number of sleepers, and then by the distance in inches between the sleepers, the modulus of elasticity of the track can be determined. It is designated by u. A continuous load of u pounds per inch of length of the rail — on each rail — will cause a deflection of 1 inch in the track.

Values determined in different cases agree fairly well : in a general way it appears that the value of the modulus increases with the weight of the rail. It is obvious that the way the track is constructed has a great influence on the value of this modulus. For the Illinois Central Railroad with 24 inches of ballast under the sleeper, the value of the modulus is 1 600 lb. With 6 inches and 12 inches of ballast, the value of the modulus is 1 000 lb. This value of u increases to 1 200 lb. with sleepers of 7×9 inches.

In service track ash ballasted 6 inches deep under the sleepers, the modulus falls to 750 lb.

For the « Champaign & Havanna branch » of the Illinois Central Railroad with 6 inches of ashes under the sleeper, and sleepers spaced 22 to 26 inches (56-lb. rails), the value of the modulus is 530 lb.

For the Delaware, Lackawanna & Western Railroad the results are not complete enough for a definite deduction to be made from them. This track is however stiffer than the Illinois and probably the value of the modulus approaches 2 200 lb. The track is ballasted with 18 inches trap rock under the sleepers with a good foundation. The sleepers are 7×9 inches $\times$ 8 ft. 6 in. and are spaced 22 inches apart.

Co-efficient of the bending moment. — In certain calculations and for making some comparisons, it may be useful to employ a *co-efficient of bending moment*, a constant by which the wheel load P is multiplied to obtain the bending moment. Generally the constant relates to the moment under the load of the wheel; if several wheels are concerned the co-efficient applies to the load of the wheel to the right of the point under consideration.

The co-efficient can also be considered as referring to the negative moment between two wheels. It is advisable in this case to say so explicitly.

The co-efficient is designated by K. If S is the stress in pounds per square inch:

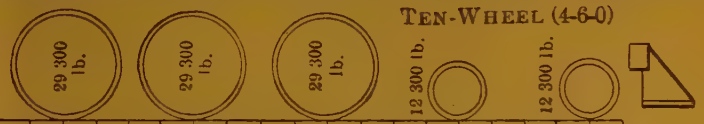
$$M = KP = \frac{SI}{c}.$$

For the negative moments between two coupled wheels, P is the mean of the two

wheel loads : between a coupled and a carrying wheel, P refers to the coupled wheel.

Table 1 gives the results of the tests on the Delaware, Lackawanna & Western Railroad.

TEN-WHEEL (4-6-0)

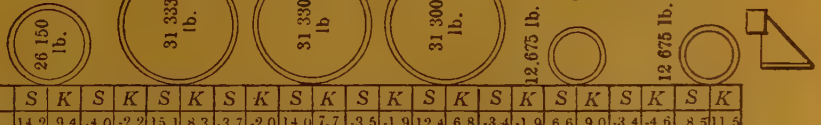


Weight of Rail, in Pounds per Yard.	Speed, in miles per hour.	S	K	S	K	S	K	S	K	S	K	S	K	S	K	S	K	S	K
105	5	14.3	8.4	-4.0	-2.4	14.4	8.5	-3.4	-2.0	12.7	7.5	-3.5	-2.1	6.5	9.1	-3.3	-4.6	8.2	11.5
	60	18.3	10.8	-5.0	-2.9	17.7	10.4	-5.2	-3.0	17.7	10.4	-4.8	-2.9	9.8	13.7	-4.9	-6.9	11.0	15.4

PACIFIC (4-6-2) PASSENGER

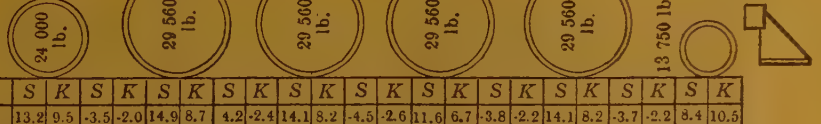
		S	K	S	K	S	K	S	K	S	K	S	K	S	K	S	K	S	K	S	K
105	5	14.6	9.0	-5.1	-2.7	13.5	7.1	-4.4	-2.3	12.7	6.6	-4.5	-2.4	13.5	7.1	-3.4	-1.8	5.9	7.8	-3.7	-4.9	7.5	9.9
	60	17.6	10.8	-6.5	-3.4	19.2	9.5	-6.3	-3.3	17.3	9.1	-6.2	-3.2	19.0	10.0	-6.0	-3.1	12.6	16.6	-5.4	-8.5	13.0	17.2

PACIFIC (4-6-2) FREIGHT



		S	K	S	K	S	K	S	K	S	K	S	K	S	K	S	K	S	K	S	K
105	5	14.2	9.4	-4.0	-2.2	15.1	8.3	-3.7	-2.0	14.0	7.7	-3.5	-1.9	12.4	6.8	-3.4	-1.9	6.6	9.0	-3.4	-4.6	8.5	11.5
	50	16.8	11.1	-5.4	-3.0	17.4	9.6	-5.0	-2.8	17.2	9.5	-4.7	-2.6	16.6	9.1	-5.5	-3.0	10.1	13.7	-5.2	-7.0	11.8	16.0

MIKADO (2-8-2)



		S	K	S	K	S	K	S	K	S	K	S	K	S	K	S	K	S	K	S	K
105	5	13.2	9.5	-3.5	-2.0	14.9	8.7	-4.2	-2.4	14.1	8.2	-4.5	-2.6	11.6	6.7	-3.8	-2.2	14.1	8.2	-3.7	-2.2	8.4	10.5
	40	13.5	9.7	-6.6	-3.8	16.7	9.7	-5.6	-3.8	16.5	9.6	-5.7	-3.3	13.6	7.9	-5.0	-2.9	14.7	8.5	-5.5	-3.2	9.9	12.4

Table 1. — Stresses in rail, *S*, and bending moment coefficients, *K*, from moving-load tests on Delaware, Lackawanna & Western Railroad.

Effect of speed. — The diagrams shew that the law of variation in relation to the speed is linear. The positive moments increase from 0.3 to 1.2 % for each mile per hour increase in speed. The differences in the variations are rather irregular and rather large according to the wheels and the section of the rails. It has not been possible to explain these differences.

It appears that the heaviest rails shew more marked variations than the lightest. It seems too that the stresses under the *Mikado* locomotive increase more quickly with the speed than the stresses under the *Pacific* and *Atlantic* locomotives. The

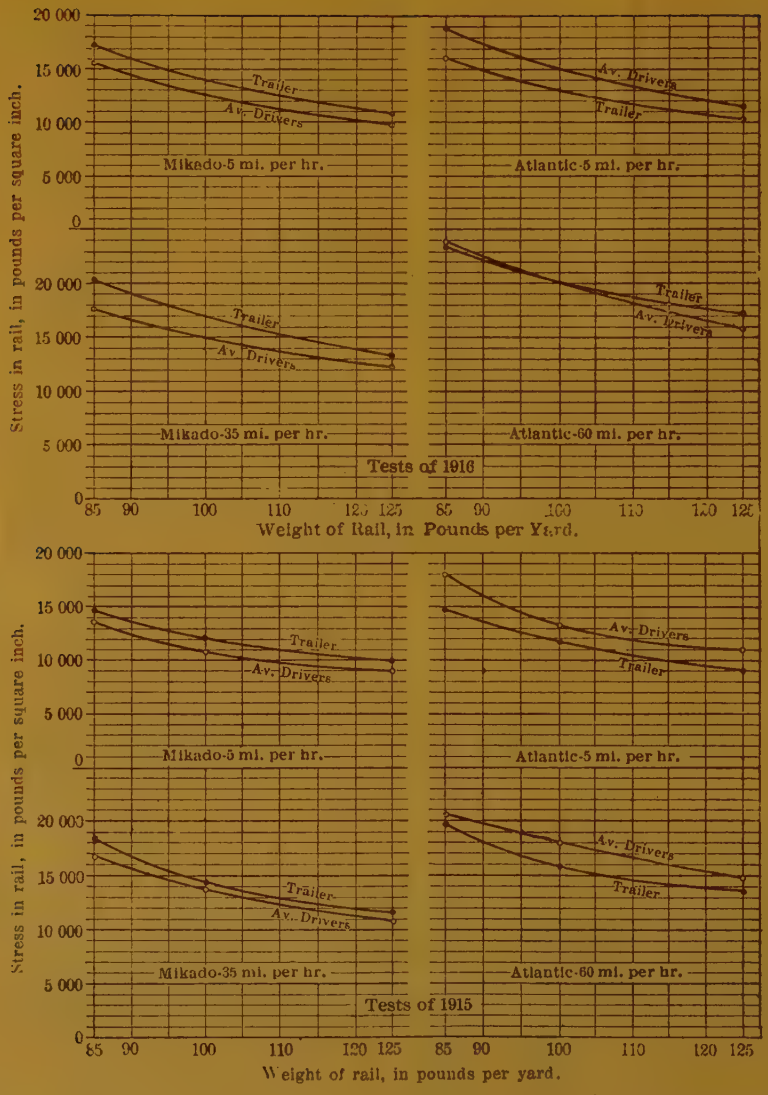


Fig. 20. — Stresses in rail for three rail sections, from tests on Illinois Central Railroad.

carrying axles and bogies also shew a more marked increase than the ordinary coupled axles.

Influence of the rail section. — In an ordinary girder, the bending moment is independent of the section of girder, and the stress is inversely proportional to the modulus of flexion $\frac{I}{c}$.

It has been found that the bending moment in the track increases with the moment of inertia of the rail.

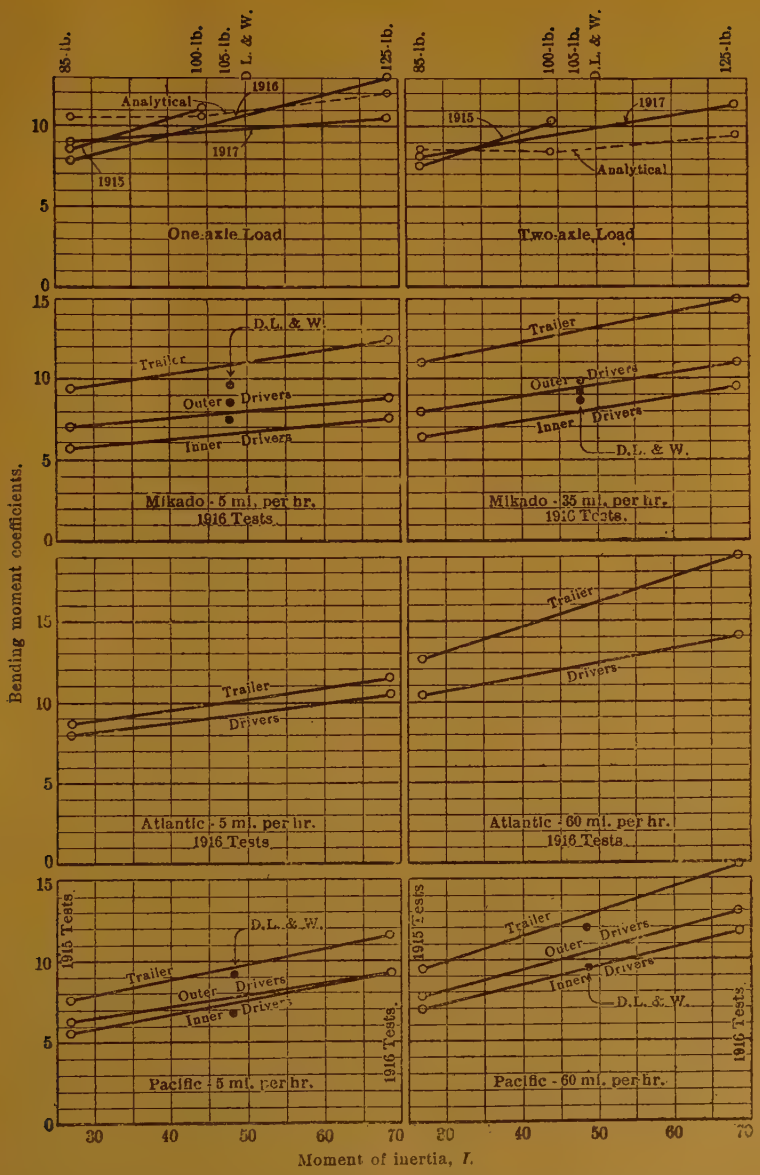


Fig. 21. — Bending moment coefficient for three rail sections.

The increase corresponding to the bigger section of rail is greater when obtained from the tests than when obtained analytically.

On the Illinois Central Railroad the increase obtained analytically is $< 10\,\%$ with 125-lb. rail as compared with 85-lb. rails. At 5 miles per hour, the tests shewed for the three locomotives increases of at least 30 % with 125-lb. rails as compar-

ed with 85-lb. rails. At higher speeds the increase would be still greater.

Effect of spacing of the loads. — A theoretical analysis shews the effect of the spacing of the loads : the tests confirmed the theoretical deductions. The diagrams of figure 21 shew that for all the locomotives, except the *Atlantic*, the co-efficients of the bending moment for the trailing carrying wheels, a considerable distance from the coupled wheels and the wheels of the leading « trucks », are greater than for the coupled wheels. In the same way the co-efficients for the coupled wheels of the *Atlantic* are greater than for the closer coupled wheels of the *Mikado*. The effect is still more marked at high speed. Although the load on the trailing carrying axle is at most 75 to 80 % of the load on the coupled wheels, the corresponding stresses are still higher, except for the *Atlantic*, and in this last case the coupled axles are farther apart, and the distance of the trailing carrying axle from the trailing coupled axle is smaller.

The analytical diagrams shew that for certain spacings the variations give rise to slight corresponding variations in the co-efficients of the moments. It should be noted that for closely spaced axles, the moment mid-way between the wheels remains positive.

These diagrams and the results of the tests are sufficient to shew the effect of the spacing of the loads.

Influence of the state of the track. — The tests were made as a rule on track properly prepared and with new sleepers, etc. It was thought desirable to make a comparison with track with badly maintained sections, ash ballast, joint sleepers in bad order, etc. The sleepers were of different kinds of wood, pine, oak, etc. 6×8 inches $\times$ 8 feet at 20-inch centres.

Track in ordinary condition, without obvious defects, gives results agreeing with those above. If the mean stress under good conditions for an isolated load acting on the sleeper is 21 000 lb. per square inch, the stress would be 26 200 on a defective sleeper.

Under moving loads (*Mikado*) the stresses increase with the speed from 20 to 40 %, and even reach 150 % at the outer edge of the foot of the rail.

Tests were also made near a sag in the track which was visible to the naked eye. (The reason given by the foreman was that the nearby joint sleepers had been packed up too much causing the middle of the rail to bend downwards).

The static deflection of the depression under the trailing coupled wheel of an *Atlantic* locomotive was found to be 0.70 inch, approximately double what it would have been with track properly packed up.

Although the programme of the tests did not include an investigation into the influence of the sleepers and the ballast, it was found that 6 or 12 inches of broken stone under the sleeper gave about the same value, but that 24 inches made a much stiffer track.

Transverse bending of the rail. — As the loads on the rail are mainly vertical and that even with a loading slightly eccentric to the perpendicular through the centre of the rail, it was thought prior to the tests that the stresses measured at the two edges of the foot of the rail would be substantially the same or, at most, with a slight difference, due to torsion.

Actually the tests with the stremmatograph shewed that the stresses measured on the two edges of the base were different, that in the outer edge being as much as double the other, revealing definitely a transverse bending of the rail.

A deformation towards the outside was also observed under the wheel, towards the interior in the adjacent spans, amounting under the wheel, to 0.01 to 0.03 inch.

This difference in the stresses was found at all speeds and generally increased with the speed.

The condition of the track has a marked effect on this bending which increases when the packing is badly done.

Table 2 — Values of the ratio of the stress at one edge of the base of rail to the mean of the stresses at the two edges. — Track with cinder ballast.

Speed in miles per hour.		85-lb. rail. 6 × 8 inches × 8 feet ties. 6 inches cinder ballast. Mikado					
5	...	1.24	1.22	1.31	1.26	1.14	1.09
15	...	1.22	1.17	1.35	1.30	1.25	1.22
25	...	1.13	1.24	1.45	1.32	1.27	1.05
30	...	1.17	1.28	1.42	1.33	1.31	1.20

To sum up, the results of the tests shew that the stress, due to the action of the wheel, is always higher at the outer edge than at the inner. They also shew that the rail bends outwards under the wheel as a rule, but that sometimes one rail bends outwards and the other inwards, which shews that there is a lateral movement of the axle. Between the wheels the deformation is towards the inside.

It is difficult to say what effect the coning of the tyre has in this connection. It must also be noted that under static tests with single loads there was little difference between the stresses.

On the average, it must be recognised that for track in good order the stress at the outside of the rail foot exceeds by 30 % the stress due to the vertical load alone.

As the modulus of transverse bending is only about 23/100 of the vertical modulus, it must be admitted that the transverse effort is not very great, the increase in stress being rather due to the low transverse modulus. This supplementary stress to the working stress of the rail must not be neglected.

Summary. — The results of the tests shew that the maximum stress that can occur on the rail in relation to the stress at low speed in a track in good repair, is given by :

$$t = t_0 (1 + a) (1 + b) (1 + c (1 + d)$$

t_0 means stress at a speed of 5 miles an hour;

$(1 + a)$ speed factor;

$(1 + b)$ factor for lateral bending;

$(1 + c)$ factor for the state of the track;

$(1 + d)$ variable co-efficient.

The value of t_0 will depend upon the locomotive and the construction of the line (sleepers, ballast, roadway).

These tests on the track have been followed up by others, and three further reports have been made by the Committee. Extracts therefrom will be given in further articles at a later date.

[656 .212 5]

Groups of sidings : calculations and comparisons,

By Piero AMIGONI,
ENGINEER.

Figs. 1 to 11, pp. 595 to 597.

(*Rivista dei Trasporti.*)

1. — When making a reasoned and detailed investigation into the layout of a yard, it is necessary to decide upon the relative position of the groups of sidings and the connecting lines, and then consider the points leading into the different groups.

The object of any such investigation is to ensure the best use of the available ground being made, that is to say, for an equal area to get the maximum length of sidings, whilst so arranging them that shunts are made on lines as short as possible so as to keep costs down to the minimum.

After having schemed out the relative arrangement of the different parts of the yard, it is as well to prepare comparative statements of the advantages each will give so as to be able to select the layout which best meets the requirements.

2. — All groups of sidings should first of all comply with the following conditions :

a) Large curves without reverse curves to be provided;

b) The group to be extended when necessary without conflicting with *a*.

There are two fundamental methods in which the points can be grouped : on a *straight* leading-in road and on a *curved* leading-in road.

The first is divided into two types as shewn in figures 1 and 2, and the second is most often used in the way illustrated in figure 3.

Other arrangements are obtained by combining the two : in practice groups with straight leading-in roads with *m* sidings can be grafted on to a curved leading-in road with *n* sidings off it (fig. 4), or conversely, a set of curved points off a straight group (fig. 5).

In the arrangements just mentioned double points have not been shewn : it is obvious that when double points are used, groups of sidings like those so far considered (figs. 6 and 7) can be provided. We shall only deal with groups of sidings corresponding to the main arrangements.

The points used in these groups are those of the Italian State Railways (mod. RA 36 S); it should be noted that these points have not been selected as being the best for the purpose, and that there may be other patterns giving better results than those at present in use in Italy. The problem has also been gone into abroad, and a German engineer, F. Ziegler, has suggested a dissymmetrical arrangement of points (lead-out from one side only of the leading-in road) (fig. 8) which has real advantages in comparison with the usual type. Whilst keeping to the Italian type of points, it will be of value to compare the

Fig. 1. — Straight group (first type).

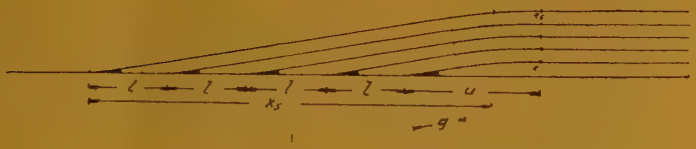


Fig. 2. — Straight group (second type).

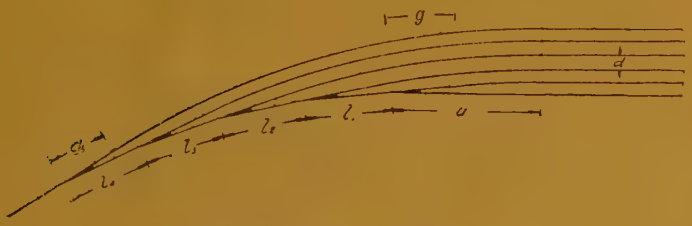


Fig. 3. — Curved group.

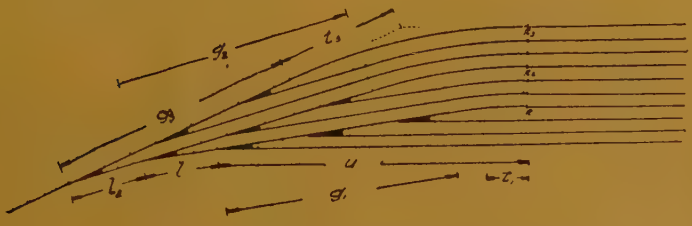


Fig. 4. — Straight groups connected by a curved group.

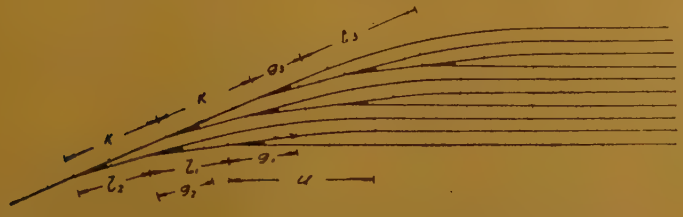


Fig. 5. — Curved groups connected by a straight group.

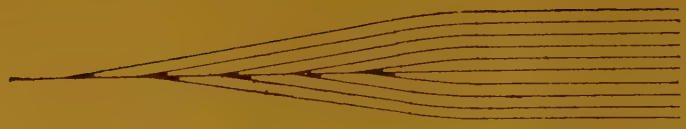


Fig. 6. — Straight group with double branches.

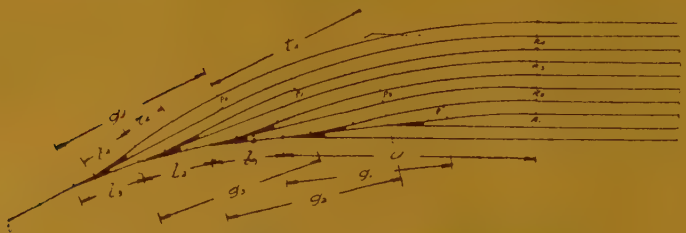


Fig. 7. — Curved group with double branches.

Fig. 8. — Double branch dissymmetrically arranged.

different arrangements of groups of sidings (1).

3. — In order that this may be done, the geometrical proportions between the different parts of the sidings should be defined. Let :

d, be the distance between centres of adjacent lines;
l, the distance between succeeding points;
t, the length of the tangent;
g, the distance between the points and the beginning of the next connecting curve;
u, the distance between the first points and the beginning of the straight lines;
x_n, the distance between the first points and the intersection of the last junction;
n, the number of branches.

(1) See also Tajani : *Trattato moderno di materiale mobile ed esercizio ferroviario* (Treatise on modern rolling stock and railway operation), vol. II.

And for mixed groups :

n, the number of branches from which are laid off the ordinary groups of
m, sidings.

When $d = 4.50$ m. (14 ft. 9 1/8 in.), and taking for the groups with branches $\text{tg } \alpha = 0.10$, the minimum radius of 350 m. (1 148 ft.), and for those with branches $\text{tg } \alpha = 0.12$, a minimum radius of 300 m. (984 ft.), the table given below can be prepared.

4. — It will now be of interest to make comparisons which will bring out the advantages of the different groups.

In doing this, groups of ten sidings will be considered :

a) Average number, maximum and minimum number of points to be passed to send a wagon from the shunting neck on to each of the sidings of the group (see diagram fig. 9).

I. . .	5.4	9	1	V. . .	3.6	5	2
II. . .	5.4	9	1	VI. . .	5.4	9	1
III. . .	5.4	9	1	VII. . .	3.9	6	2
IV. . .	3.6	5	2				

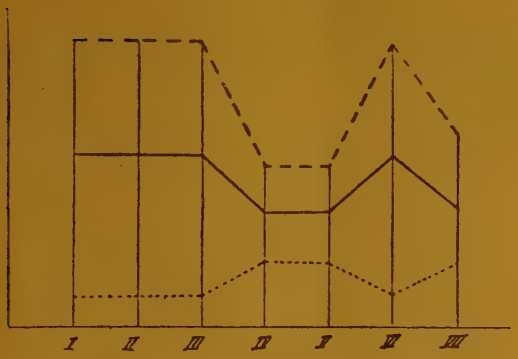


Fig. 9.

——— Mean number of branches.
— — — — Maximum number of branches.
..... Minimum number of branches.

b) Length of serviceable track in the different groups with equal occupied area. The calculation is only approximatively correct. The area occupied in the group is that inside the axis of the outer lines. Area occupied 16 400 m² (19 610 square yards). (See diagram fig. 10).

	Metres (feet).			Metres (feet).
I . .	1 710	(5 610)	V . .	3 950 (12 960)
II . .	1 710	(5 610)	VI . .	3 820 (12 530)
III . .	3 860	(12 660)	VII . .	3 850 (12 630)
IV . .	3 610	(11 840)		

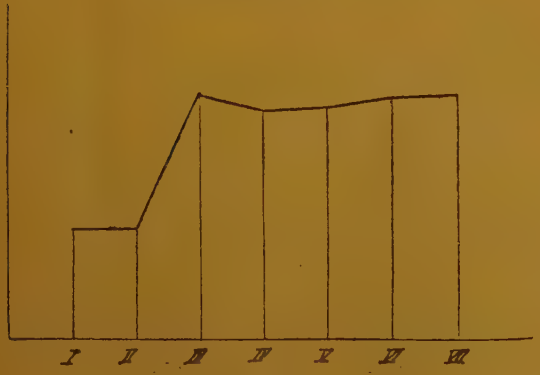


Fig. 10.

c) Mean, maximum and minimum length passed over to send a wagon on each line. (The length is measured from the point at the beginning of the branch to the last sleeper). (See diagram fig. 11.)

	Metres (feet).	Metres (feet).	Metres (feet).
I.	247.5 (812.0)	48.5 (159.1)	410.8 (1 347.8)
II.	257.5 (812.0)	48.8 (160.1)	410.6 (1 347.1)
III.	178.3 (585.0)	48.8 (160.1)	348.6 (1 143.7)
IV.	155.9 (511.5)	93.6 (307.0)	218.4 (716.5)
V.	151.9 (498.3)	84.2 (276.2)	210.7 (691.3)
VI.	153.7 (504.2)	48.6 (159.4)	230.9 (757.6)
VII.	130.0 (426.5)	60.5 (198.5)	201.4 (660.8)

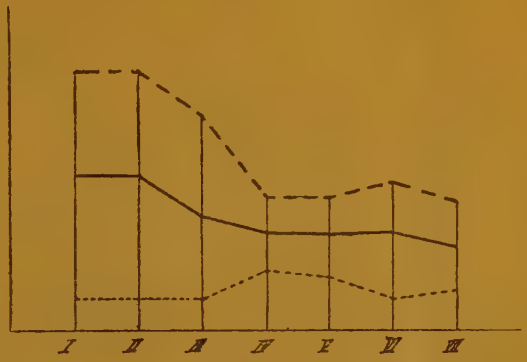


Fig. 11.

——— Mean length.
— — — — Maximum length.
..... Minimum length.

A study of the diagrams shews that the best arrangements of sidings for marshalling purposes are those of types III, IV, V, VI, VII, which give about equal length of sidings, and for shunting out wagons types IV, V, and VII, as the average length passed over is small, the number of points met is limited and close together. The diagrams shew the far from negligible advantages to be obtained by sidings suitably laid out for the required purpose in place of those usually adopted because they are simpler (I, II).

Characteristics of the groups.

Formulæ applied.	Numerical values	
	for tg α = 0.10	for tg α = 0.12
I. — *Straight group.* — *First type.*		
$l = \frac{d}{\sin \alpha}$	45.224 m.	37.769 m.
$R \leq \left(\frac{d}{\sin \alpha} - q\right) \operatorname{cotg} \frac{\alpha}{2}$	554.575 m.	392.500 m.
$g = \frac{d}{\sin \alpha} - R \operatorname{tg} \frac{\alpha}{2}$	27.768 m.	19.833 m.
II. — *Straight group.* — *Second type.*		
$l = \frac{d}{\sin \alpha}$	45.224 m.	37.769 m.
$R_1 \leq \left(\frac{d}{\sin \alpha} - q\right) \operatorname{cotg} \frac{\alpha}{2}$	554.575 m.	392.500 m.
$g = \frac{d}{\sin \alpha} - R_1 \operatorname{tg} \frac{\alpha}{2}$	27.768 m.	19.833 m.
$u = d \operatorname{cotg} \alpha + R_1 \operatorname{tg} \frac{\alpha}{2}$	62.456 m.	55.436 m.
$x_n = nd \operatorname{cotg} \alpha$	$n \cdot 45$	$n \cdot 37$
III. — *Curved group.*		
l_1 (1) $= 2R_1 \operatorname{tg} \frac{\alpha}{2}$	34.912 m.	35.872 m.
l_n (2) $= l_1 + 2(n-1)d \operatorname{tg} \frac{\alpha}{2}$		
34.912 m. $+ (n-1)\, 0.44877$	35.872 m. $+ (n-1)\, 0.53808$	
$g_1 = \frac{d}{\sin \alpha} - R_1 \operatorname{tg} \frac{\alpha}{2}$	27.768 m.	19.833 m.

(1) This ratio is obtained by noting that $l_1 = 2t_1$, when R_1 is the radius of the circle tangent to the direct lines of the three first branches. From the ratio giving l_1, we find when L is the length of the branch :

$$l_1 \text{ min.} = L, \qquad R_1 \text{ min.} = \frac{L}{2} \operatorname{cotg} \frac{\alpha}{2}.$$

(2) This ratio is found by noting that the radii of the circles tangent to the successive groups of branch sidings (1, 2, 3, 4, 5, etc.) vary from $2l$ in turn.

Characteristics of the groups. (*Continued.*)

Formulæ applied.	Numerical values	
	for tg $\alpha = 0.10$	for tg $\alpha = 0.12$
III. — *Curved group.* (Continued.)		
g_n [1] $= g_1 - (n-1)\, d \operatorname{tg} \frac{\alpha}{2}$		
27.768 m. $- (n-1)$ 0.224435	19.833 m. $- (n-1)$ 0.26904	
$u = d \operatorname{cotg} \alpha + R_1 \operatorname{tg} \frac{\alpha}{2}$	62.456 m.	55.436 m.
IV. — *Straight groups connected by means of a curved group* [2].		
$l_1 = 2R_1 \operatorname{tg} \frac{\alpha}{2}$	34.912 m.	35.872 m.
$l_n = l_1 + 2m\,(n-1)\, d \operatorname{tg} \frac{\alpha}{2}$ and for $(m = 3)$		
34.912 m. $+ (n-1)$ 1.34651	35 872 m. $+ (n-1)$ 1.61424	
$g_1 = \frac{md}{\sin \alpha} - R_1 \operatorname{tg} \frac{\alpha}{2}$	118.216 m.	95.371 m.
$g_m = g_1 - m\,(n-1)\, d \operatorname{tg} \frac{\alpha}{2}$		
118.216 m. $- (n-1)$ 0.67325	95.371 m. $- (n-1)$ 0.80712	
$t_1 = R_1 \operatorname{tg} \frac{\alpha}{2}$	17.456 m.	17 936 m.
t_n [3] $= R_n \operatorname{tg} \frac{n\alpha}{2}$ $(n = 2)$	36.350 m.	37.620 m.
$(n = 3)$	56.786 m.	59.214 m.
V. — *Curved groups connected by means of a straight group.*		
$l_1 = 2R_1 \operatorname{tg} \frac{\alpha}{2}$	34.912 m.	35.872 m.
$l_m = l_1 + 2\,(m-1)\, d \operatorname{tg} \frac{\alpha}{2}$		
34.912 m. $+ (m-1)$ 0.44887	35.872 m. $+ (m-1)$ 0.53808	
$g_1 = \frac{d}{\sin \alpha} - R_1 \operatorname{tg} \frac{\alpha}{2}$	27.768 m.	19.833 m.
$g_m = g_1 - (m-1)\, d \operatorname{tg} \frac{\alpha}{2}$		

(1) If q be the distance between the points and the end of the branch, we get : g min. $= q$, from which N max. is easily found.

(2) The formulæ applied to this group are obtained by putting in those for the curved groups md in place of d.

(3) Actually $Rn = R_1 + m\,(n-1)\, d$[1].

Characteristics of the groups. (*Continued.*)

Formulæ applied.	Numerical values	
	for tg $\alpha = 0.10$	for tg $\alpha = 0.12$
V. — *Curved groups connected by means of a straight group.* (Continued.)		
$27.768 \text{ m.} - (m-1)\,0.224435$	$19.833 \text{ m.} - (m-1)\,0.26904$	
$t_1 = \frac{l_1}{2}$	17.456 m.	17.936 m.
$t_m = R_m \operatorname{tg} \frac{m\alpha}{2}$ $(m=2)$	35.450 m.	36.540 m.
$t_m = R_m \operatorname{tg} \frac{m\alpha}{2}$ $(m=3)$	54.074 m.	55.955 m.
$k = \frac{nd}{\sin m\alpha}$ $(m=3)$	45.861 m.	38.497 m.
$u = d \operatorname{cotg} \alpha + R_1 \operatorname{tg} \frac{\alpha}{2}$	62.456 m.	55 436 m.

VI. — *Straight group of double branches.*

The formulæ relative to a straight group of single branches, second type, apply to this case, but we should have $l_1 = \frac{d}{\sin \alpha} \geqslant L$, L being the length of the double branch.

VII. — *Curved group of double branch lines* (1).

$l_1 = 2R_1 \operatorname{tg} \frac{\alpha}{2}$		34.912 m.	35.872 m.
$l_n = l_1 + 4\,(n-1)\,d \operatorname{tg} \frac{\alpha}{2}$			
$34.912 \text{ m.} + (n-1)\,0.89774$		$35.872 \text{ m.} + (n-1)\,1.07616$	
$R_n = R_1 + 2(n-1)\,d$		$350 + (n-1)\cdot 9$	$300 + (n-1)\cdot 9$
$t_n = R_n \operatorname{tg} \frac{n\alpha}{2}$	$n=1$	17.456	17.872
	$n=2$	35.900	37.080
	$n=3$	55.431	57.585
	$n=4$	76.160	79.627
$g_1 = \frac{2d}{\sin \alpha} - t_1$		72.992	57.666
$g_n = g_1 - 2\,(n-1)\,d \operatorname{tg} \frac{\alpha}{2}$			
$72.992 - (n-1)\,0.44887$		$57.666 - (n-1)\cdot 0.53808$	

(1) This group is obtained by means of a group like those with single branches with a distance between lines equal to $2d$. Consequently n is the number of double branches.

When laying in the second line in to the points, connecting curves are used in which ρ_n represents the radii, T_n the corresponding tangents, γ_n the distances from the centre of the second lines to the beginning of the connecting curve.

Characteristics of the groups. (*Continued.*)

Formulæ applied.	Numerical values	
	for tg $\alpha = 0.10$	for tg $\alpha = 0.12$
VII. — *Curved group of double branches.* (Continued.)		
$\rho^1 = (g_1 - \delta\,(^1) - d \operatorname{cotg} \alpha) \operatorname{cotg} \frac{\alpha}{2}$		
	326.785	202.941
$\rho n = \rho_1 - 2\,(n-1)\,d$		
326 785 m $-(n-1)\cdot 9$	202.941 m. $-(n-1)\cdot 9$	
$\tau_1 = \rho_1 \operatorname{tg} \frac{\alpha}{2}$	16.298 m.	12.133 m.
$T_n = T_1 - 2\,(n-1)\,d \operatorname{tg} \frac{\alpha}{2}$		
16.298 m. $-(n-1)$ 0.44887	12.133 m. $-(n-1)$ 0.53808	
$\gamma_1 = \frac{d}{\sin \alpha} - T_1$	28.926 m.	25.636 m.
$\gamma n = \gamma_1 + 2\,(n-1)\,d \operatorname{tg} \frac{\alpha}{2}$		
$28.926 + (n-1)$ 0.44887	$25.636 + (n-1)$ 0.53808	
$u = 2d \operatorname{cotg} \alpha + t$	107.456	92 872

(1) δ_1 is the distance between the centres of the double branch lines.

[625 .13 (.73)]

Designing a ventilation system for a vehicular subway in California,

By Merton C. COLLINS,

STRUCTURAL AND VENTILATING ENGINEER, ESTUARY SUBWAY, OAKLAND, CALIFORNIA.

Figs. 1 to 7, p. 603 to 612.

(From *Engineering News-Record.*)

Because ventilation requirements govern many features of the structural design and even chief features of a subway project as a whole, proper provision for the ventilation of vehicular subways can be made only after much preliminary study. In order to secure an economical structure, therefore, the ventilation design should be concurrent with and closely co-ordinated with the structural design. This is the policy that was followed in working out the ventilation and structural features of the Oakland estuary subway described in the following.

The design of the subway was actively

commenced in September, 1923, with the author engaged to carry on the ventilation studies and design, and the structural design of the equipment buildings. In beginning work on this project the author was impressed by the fact that, despite the enormous growth of motor vehicle traffic in the United States in recent years, prior the work on the estuary tube scientific methods of ventilation had been applied on only two large vehicular tunnels, or subways, the Holland Tunnel in New York and the Liberty Tunnel in Pittsburgh. In view of the complexe traffic problems to be solved in many congested localities, it is highly probable that the number of ventilated vehicular subways will materially increase in the next few years.

The transverse method of ventilation was adopted for the Oakland estuary subway after natural ventilation and longitudinal ventilation had been considered and rejected. Natural ventilation, such as is used in some European vehicular tunnels, was not found feasible because of smoke and gases. Longitudinal ventilation, as used in steam and electric train tunnels and in mine tunnels, was rejected for six reasons : 1. In tunnels so ventilated, the pollution of the air gradually increases from the point of entry of the fresh air to the point of exit of the vitiated air. If this maximum allowable, degree of pollution is obtained only at the exit, it is evident that there is a great waste of supplied air and power throughout the greater portion of the subway. 2. There will be a noticeable draft due to the high velocity of the large volume of air necessary to ventilate the entire length of subway roadway. 3. There is a great fire hazard of flames spreading along the entire line of vehicles in case of a fire and traffic jam, with the accompanying hazard of having the entire length of subway filled with smoke and interfering with relief work. 4. Large quantities of air could be sent through the roadway section, as a duct, only with excessive power, which would be costly. 5. Two lines of traffic moving in opposite directions are not feasible, owing to the churning effect and air eddies, unless the lanes are separated by a partition. 6. Considerable discomfort would be experienced by passengers in open cars driving against the current or exposed to smoke and gases present.

In the transverse method, as used, in the Holland Tunnel in New York, the air, both fresh and vitiated, is to be carried in large ducts separated from the roadway and is to be kept under pressure which will force it continuously across the roadway, transverse to the direction of traffic, the rising, vitiated air being exhausted through the ceiling. Advantages of the method are : 1. All air throughout the subway is of the same degree of pollution, requiring the minimum amount of fresh air, which is about 50 % of the quantity of fresh air required for a longitudinal ventilation system that would permit the same degree of pollution. 2. No draft is noticeable to the passengers as the movement of the air is vertical and spread over the entire width of roadway. The high velocity of air occurs only in the large main air ducts, which are separaed from the roadway. 3. In case of a fire and a traffic jam, the fire is localized and prevented from spreading due to the air currents being upward and not along the line of traffic. In such a case the exhaust fans may be speeded up to withdraw more quickly the localized smoke. 4. The air may be supplied from several different sources, making the system more flexible and reducing the power cost. 5. It is equally adaptable to traffic in either or both directions. 6. Passengers get the maximum degree of comfort because the vitiated air in rising to the ceiling passes the breathing zone once only.

The estuary subway is to be entirely of reinforced concrete and has a total

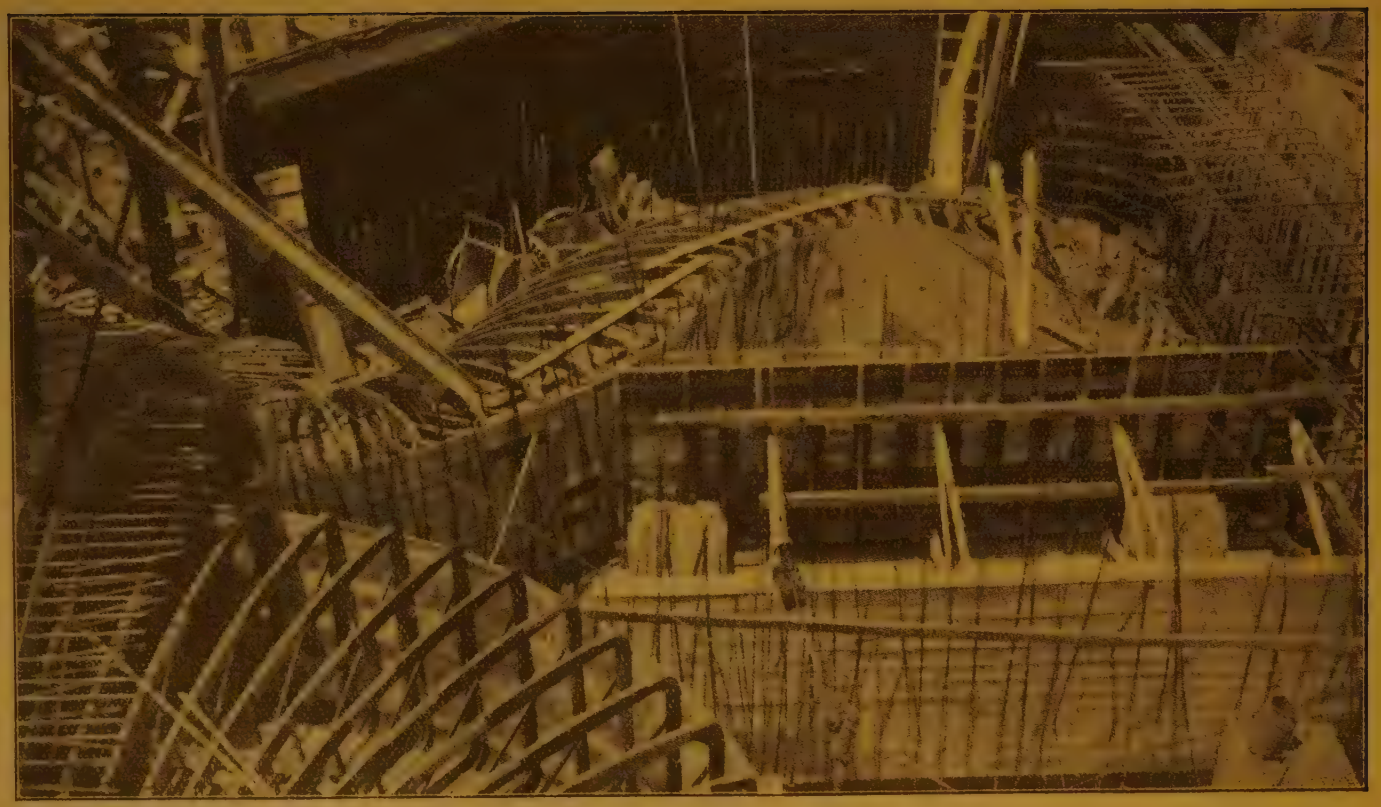
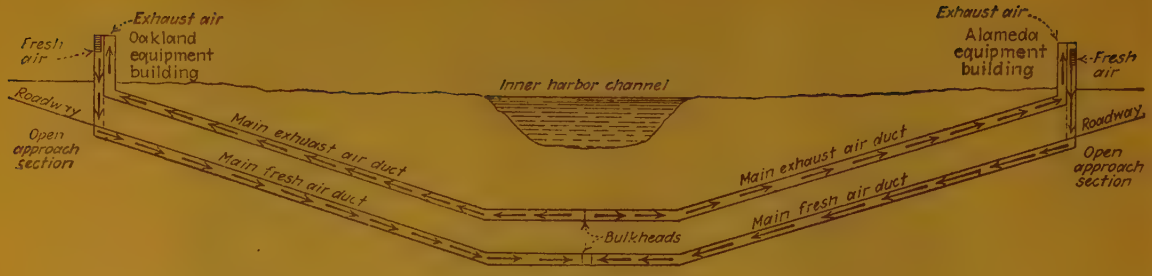
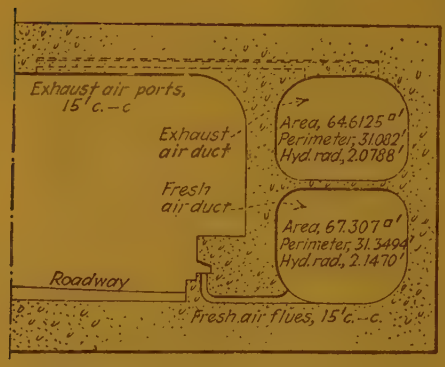


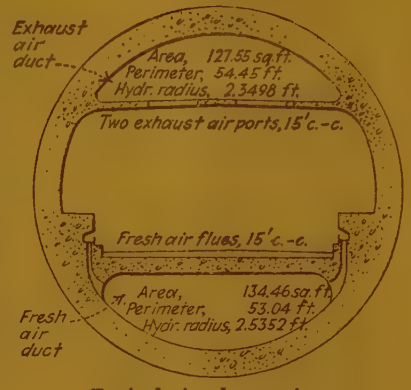
Fig. 1.5— Forms for curved vitiated air ducts in transition structure.



Ventilation distribution.



Typical half-section of rectangular subway.



Typical circular section.

Fig. 2 — Scheme of distribution and typical duct sections.

length of 4 435 feet of which 3 545 feet is covered and requires ventilation, and 890 feet is in open approach cuts. Commencing at Sixth and Harrison Streets in Oakland, the subway, which is located on the center line of Harrison Street, descends southerly on a 4.59 % grade to a level at which the roadway is about 68 feet below mean lower low water in the estuary, continues thence 725 feet on flat grades across and under the estuary and then ascends on a 4.50 % grade, curving to the center line of Webster Street near Tynan Avenue, in Alameda.

The covered portion being located, in part, under city streets, the shapes of the various sections are varied to suit the ground and ventilation conditions. The most economical and desirable section of a subway structure, from a structural and ventilation standpoint, is circular, with the segmental-shaped fresh-air duct below the roadway and the segmental-shaped vitiated-air duct above the roadway ceiling slab. This circular structure was used in the greater part of the estuary tube. On the Oakland side, where the structure is located along and under Harrison Street, a circular structure was out of the question, however, due to the lack of sufficient headroom. It thus became necessary to design a rectangular structure for this location until a depth of covering was reached which would make a circular section possible. The rectangular section has two square fresh-air ducts and two similar shaped vitiated-air ducts, one of each type located on either side of the roadway.

The transition from the rectangular to the circular structure was rather complicated both in design and construction. However, a complete transition from the main rectangular air ducts on the sides of the roadway, to segmental-shaped ducts above and below the roadway was accomplished in a length of 37 feet without loss of cross-sectional area or encroachment on the roadway area, with very little added friction loss and on easy curves. The large air ducts change position through double reverse curves and also change shape from square to half-segmental sections.

In general, the subway is divided into three main longitudinal divisions extending from portal to portal : 1. the roadway for vehicular traffic having a maximum width of 32 feet, including a sidewalk on either side, and a roadway proper of 22 ft. 10 in. wide between curbs; 2. the main fresh-air ducts located below or to the sides of the roadway; and 3. the main vitiated-air ducts located over or at the sides of the roadway. A transverse partition bulkheads the main air ducts about midway between the portals, thus dividing the ventilating system into two separate units, one operated from the Oakland portal building and the other from the Alameda portal building.

The fresh air is to be forced through ducts a distance of approximately 1 700 feet from each portal to the bulkhead midway in the tube. The fresh-air ducts on the Oakland side on leaving the portal building are on opposite sides of the roadway and are square in shape for a distance of 360 feet until they reach the transition structure. Here the fresh-air ducts change from the sides to a position beneath the roadway, and change shape from the square to the half-segmental section which shape they maintain, separated by a center wall, until the bulkhead is reached. On the Alameda side from the portal building to the bulkhead a large segmental-shaped air duct under the roadway is maintained without change of shape or position.

Being under pressure, the air is to be forced into the continuous expansion chambers through 6 × 42-inch air flues spaced at 15-foot intervals longitudinally on both sides of the roadway. The openings of these flues into the expansion chambers are to be adjusted by means of asbestos board slides by amounts to be determined by the static pressure curve of the main duct. The air from these flues is to be forced into continuous expansion chambers of trapezoidal shape, located a few inches above the roadway curbs. The outside faces of these chambers are continuous steel plates, which are adjustable, the openings at the top forming a continuous slot through which the air is to be forced out into the roadway in a continuous sheet under the bodies of the passing vehicles. The width of opening in these slots ranges from 1/4 to 2 1/2 inches and will be determined by the static pressure curve of the duct.

The vitiated air is to be withdrawn into the main vitiated-air ducts through pairs of exhaust ports in the ceiling slab spaced at 15-foot intervals longitudinally. These ports have a maximum opening of 5 1/2 × 72 inches by means of zinc slides which adjust the opening to any width within the 5 1/2-inch limit. The amount of opening to be provided at the various ports is to be determined from the static pressure curves of the main vitiated-air ducts.

The vitiated-air duct is segmental in shape on the Alameda side from the bulkhead to the portal building. On the Oakland side the vitiated air duct is segmental in shape from the bulkhead to the transition structure, where it is divided into two half-segmental shaped ducts gradually changing to a square shape and changing position from over the roadway to the sides of the roadway from that point to the portal building.

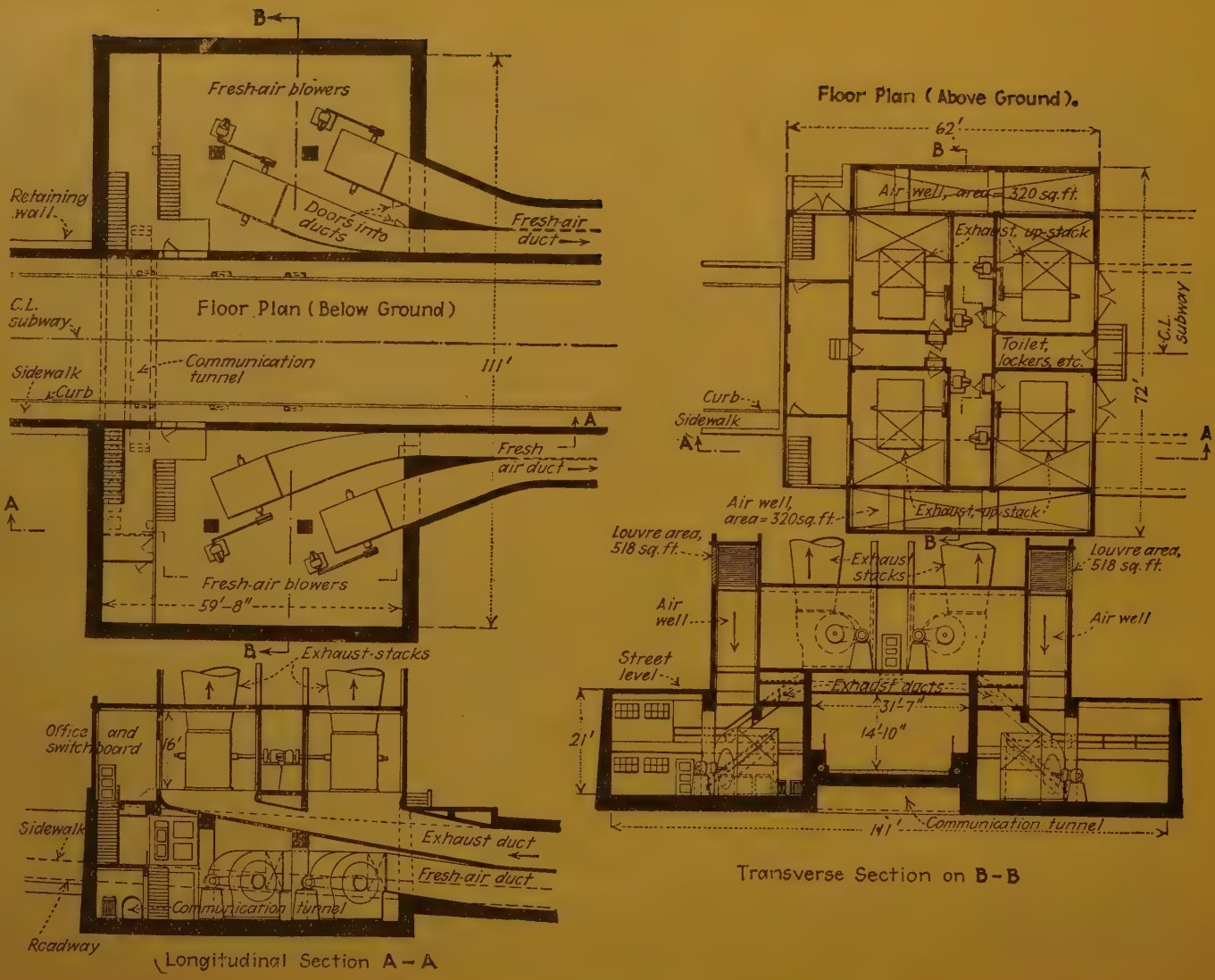


Fig. 5. — Plan and elevation of ventilation equipment building.

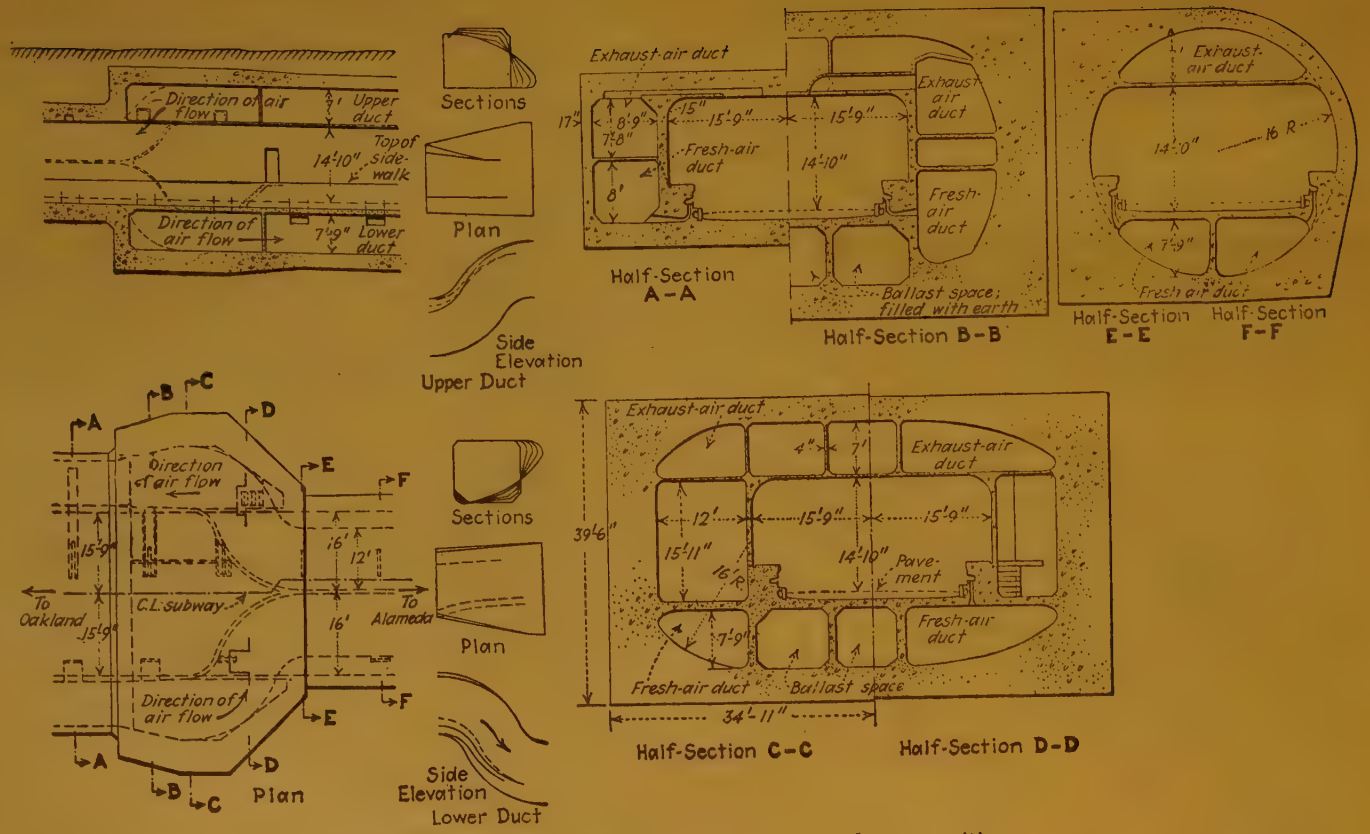


Fig. 4. — Plan and sections of ventilating duct transition.

It was originally intended to place the ventilation equipment buildings at the quarter points of the covered portion, and to ventilate the subway for a quarter of the length in each direction from each building. Prior to the detailed studies this appeared to give the best air distribution system, although it meant very large and deep sub-surface equipment structures. However, ventilation studies showed conclusively that if these structures were designed of a size that it would be practicable to construct, the air losses, due to small air ducts and complicated elbows at the source of air supply, would increase the power requirements to a prohibitive amount. Further studies by the author showed that by placing the equipment buildings at the portals and ventilating half of the subway from each building, not only would their cost, size, depth and construction difficulties be enormously decreased, but the ventilation system would be more direct and positive and the power requirements would be greatly reduced. Also, the source of fresh air being thus removed from the proximity of passing trains on First Street the air would not be polluted by smoke and would not need to be washed. In addition, the equipment buildings being built at and around the portals would afford, with proper architectural treatment, monumental entrances to the subway in each city.

The ventilation equipment buildings as finally designed consist of subsurface structures divided into two large chambers on either side of the roadway to house the large fresh-air fans, which will draw their supply of air into the chamber from the atmosphere through large air wells extending into the superstructure and having louvers through their walls. The fresh air will not be washed, owing to the absence of factories or steam trains in the vicinity of the portal buildings. Transformers, switchboards, motors and other equipment will also be housed in these buildings. The large exhaust fans are to be housed in the superstructure, each fan being located in a separate gas-tight room, having large floor openings, with damper doors, connecting with the large vitiated-air chamber below the main floor.

Upon reaching the portal buildings the vitiated air is expanded, with the loss of all velocity pressure, into large vitiated-air chambers located under the exhaust fan room floors. The vitiated air is to be exhausted from the building through curved « évasé » stacks into the atmosphere a point sufficiently removed from the fresh air louvers to prevent the short-circuiting of the vitiated air with the fresh air. The exhaust fan rooms, fresh air wells, exhaust stacks and operators' control room are all combined in a structure directly above and overlooking the approach. The operator from his outlook and with the communicating signal and telephone system will have complete control of traffic at all times and in addition to his normal duties of supplying ventilation to meet the needs of the traffic can furnish emergency ventilation in case of a fire and traffic jam and perform such other duties as may be necessary to safeguard the traffic.

At frequent intervals throughout the subway, particularly at points where the shapes of the air ducts change, air measurement stations are located. These are constructed by placing a series of ferrules at close intervals in the walls of air ducts through which instruments are inserted and the area of the ducts traversed and the center constants determined. After the characteristics of the ducts are determined further readings are taken by pitot and piezometer tubes in stations located at various points through the subway where velocity pressure, static pressure and total pressure may the determined as desired. When the fans are installed extensive

readings will be taken to determine the final adjustments to be made on the width of openings of the various fresh air flues, continuous slot and exhaust ports and also as a check on the formulas used.

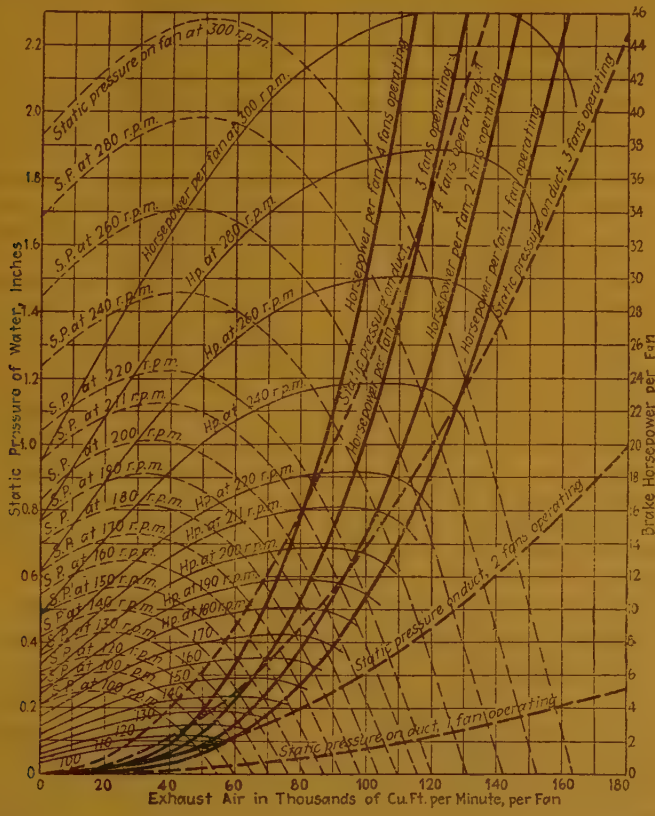

Static Pressure of Water, Inches
Brake Horsepower per Fan
Exhaust Air in Thousands of Cu.Ft. per Minute, per Fan
Static pressure on fan at 300 r.p.m.
Horsepower per fan at 300 r.p.m.
S.P. at 280 r.p.m.
S.P. at 260 r.p.m.
S.P. at 240 r.p.m.
S.P. at 220 r.p.m.
S.P. at 200 r.p.m.
S.P. at 180 r.p.m.
S.P. at 170 r.p.m.
S.P. at 160 r.p.m.
S.P. at 150 r.p.m.
S.P. at 140 r.p.m.
S.P. at 130 r.p.m.
S.P. at 120 r.p.m.
S.P. at 110 r.p.m.
S.P. at 100 r.p.m.
Hp. at 280 r.p.m.
Hp. at 260 r.p.m.
Hp. at 240 r.p.m.
Hp. at 220 r.p.m.
Hp. at 211 r.p.m.
Hp. at 200 r.p.m.
Hp. at 190 r.p.m.
Hp. at 180 r.p.m.
170
160
150
140
130
120
110
100
Static pressure on duct, 3 fans operating
Horsepower per fan, 3 fans operating
Static pressure on duct, 4 fans operating
Horsepower per fan, 4 fans operating
Horsepower per fan, 2 fans operating
Brake pressure on duct, 3 fans operating
Horsepower per fan, 1 fan operating
Static pressure on duct, 2 fans operating
Static pressure on duct, 1 fan operating

Fig. 5. — Typical chart of characteristic ventilation curves.

It is proposed to install the automatic carbon monoxide recorder and alarm, which has been recently developed by the United States Bureau of Mines. By means of this instrument a continuous record graph is kept of the concentration of carbon monoxide in the subway air. The instrument may be electrically connected to an alarm or to the switchboard and more power may automatically be furnished to the fans should the concentration of carbon monoxide exceed that allowed. The principle upon which this instrument operates is the registering by means of thermocouples and a potentiometer of the heat generated by the chemical union of carbon monoxide and oxygen.

As a result of extensive experiments carried on by the New York and New Jersey State Bridge and Tunnel Commission and the United States Bureau of Mines in their experimental tunnel at Bruceton, Pa., and later from tests on actual traffic in the Liberty Tunnel at Pittsburgh, Pa., the amount of carbon

monoxide, which is the poisonous constituent of motor exhaust gases, has been accurately determined. These tests cover various types of cars, loadings, weather conditions, speeds and roadway grades. It has further been found, as the result of extensive tests on volunteer subjects made for the tunnel commission by Dr. Yardell Henderson, of Yale University, that when human beings are subjected to motor exhaust gases diluted to a concentration of 4 parts of carbon monoxide to 10 000 parts of fresh air for a period not exceeding one hour, no noticeably harmful effect is apparent. This concentration of 4 : 10 000 is approved by the U. S. Bureau of Mines as permissible for public safety, and is the standard adopted as the maximum degree of pollution in working out ventilation problems on the estuary subway.

A feature of the design is the connection between the sidewalk pipe rail and the expansion chamber at frequent intervals whereby a small supply of fresh air is provided for the use of traffic police, who may be stationed in the subway for long periods of time and for passengers who may be temporarily overcome in accidents.

From a study of past and present vehicular traffic counts to and from Alameda, over the Webster Street bridge, which is to be replaced by the estuary subway, the amount, distribution and variation of traffic were determined and an operating schedule adopted.

Traffic through the subway is to be under the control of traffic police at all times, and, accordingly, computations were based on traffic in two lines moving in opposite directions at 10 miles per hour and spaced 40 feet apart in each line. On this basis table I indicates the amount of carbon monoxide to be exhausted and the fresh air required to properly dilute it, for the level and the average of up and down 4 1/2 % grades.

TABLE I. — **Quantities of carbon monoxide and fresh air.**

—	Per cent.	Cubic feet of CO per hour per foot of subway.		Cubic feet of fresh air per minute per foot.	
		Level.	Grade.	Level.	Grade.
5-passenger cars.	30	0.660	0.713	27.50	29.71
7-passenger cars.	20	0.760	0.893	31.67	37.21
Trucks, 1 1/2 tons or less. . . .	15	0.443	0.480	18.46	20.00
Trucks, 1 1/2 tons to 3 tons. . .	15	0.780	0.790	32.50	32.92
Trucks, 3 1/2 tons to 4 1/2 tons .	10	0.740	0.615	30.83	25.63
Trucks, 5 tons and over	10	0.760	0.723	31.67	30.13
Totals. . .	100	4.143	4.214	172.63	175.60

The fact that the computations have been made on the above basis should not be misconstrued to mean that such speed and car spacing must be adhered to. This set of assumptions was used and carried through consistently to give known points on the characteristic curves from which, knowing the equations of the curves, it is a simple matter to compute any quantity or for any demand up to capacity of the equipment.

Each equipment building has been

designed to accommodate four large fresh air fans and four large exhaust fans. As the air quantities are large and the static pressures relatively low, the fans selected have backward-curved blades which will operate in parallel on the same duct at different speeds. At the present time sufficient air supply will be furnished by half the total number of fans, to be driven by four-speed alternating-current 3-phase squirrel-cage induction motors of 5 to 75 H. P. As traffic increases and more air is required, more fans will be added. This ultimate installation will furnish over 1 000 000 cubic feet of air per minute and exhaust the same amount, together with the increment added due to the higher temperature of the vitiated air. These figures are based on ventilation for full capacity traffic in both lines at a speed of between 25 and 30 miles per hour. Upon the opening of the subway the speed of traffic will be regulated according to needs. It is not believed, however, that the full demand on the ventilating equipment will be reached within twenty years, by which time other arteries of travel will doubtless be provided.

The most important objection to be raised against mechanically ventilated subways is the hazard of possible interruption of power to drive the fans. To minimize this hazard the estuary subway is to be directly connected to four independent sources of power, two hydro-electric and two steam plants, which are interconnected by automatic switches. A calamity of such major proportions as would interrupt all four sources of power, would naturally be sufficiently serious to justify drastic traffic control.

Assuming a minimum spacing of cars in the line of traffic the following interesting fact regarding economy of ventilation is apparent : For traffic of such density that the subway will be continuously filled, the most economical ventilation operation will obtain with the lowest speed allowed. Also, for any traffic density less than that which will continuously fill the subway, greater economy will result by speeding up the traffic, which permits the few cars to remain in the subway a minimum length of time. Table II shows this variation for two cases taking cars with minimum spacing of 40 feet in each line.

When transverse ventilation was adopted for so long a tube as the Holland tunnel it was found that the ordinary ventilation formulas, as commonly used in building and tunnel ventilation, would not answer. Requirements of the Holland tunnel were that the air should be

TABLE II. — **Ventilation variation for full capacity and less-than-capacity.**

Speed of traffic, in miles per hour.	Full capacity traffic.				Less than capacity traffic.			
	Number of cars passing per hour.	Spacing in each line, in feet.	Cubic feet of CO per hour.	Fresh air, cubic feet per minute.	Number of cars passing per hour.	Spacing in each line, in feet.	Cubic feet of CO per hour.	Fresh air, cubic feet per minute.
6	1 584	40	10 280	428 500	1 583	40	10 275	428 100
10	2 640	40	15 390	641 280	1 583	66.7	9 230	384 590
15	3 960	40	17 980	761 020	1 583	100	7 190	299 590
20	5 280	40	22 620	942 720	1 583	132.4	6 780	282 500
25	6 600	40	26 030	1 084 570	1 583	166.6	6 250	260 410
30	7 920	40	28 550	1 189 480	1 583	200	5 710	237 920

uniformly supplied and exhausted at close intervals throughout the length of a system using large ducts and great quantities of air at relatively low pressure. In order to develop satisfactory working formulas the New York and New Jersey Bridge and Tunnel Commission worked in conjunction with the

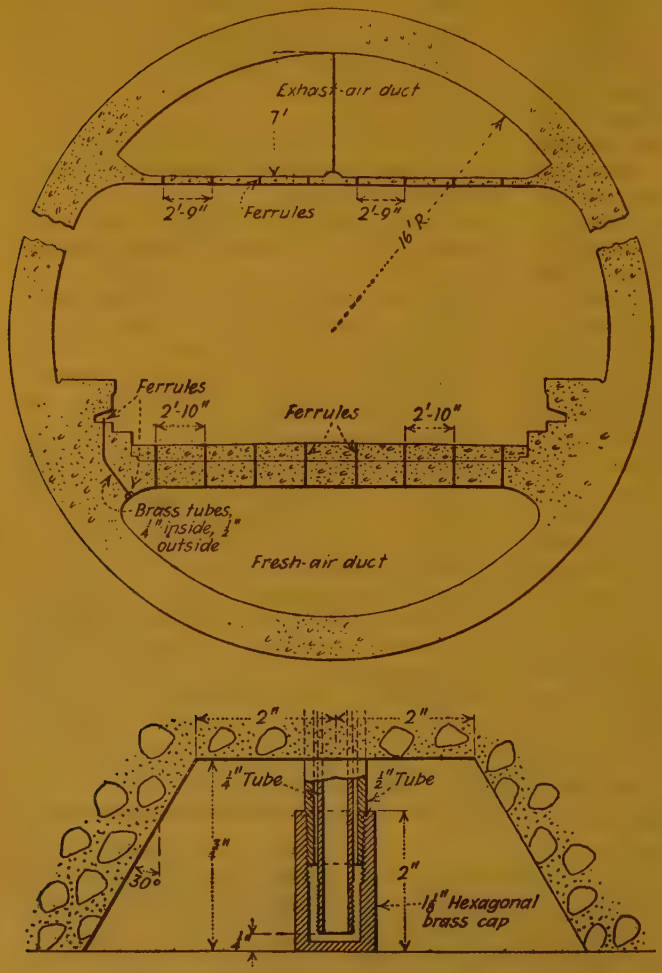


Fig. 6. — Typical air traversing station and one of several types of ferrules.

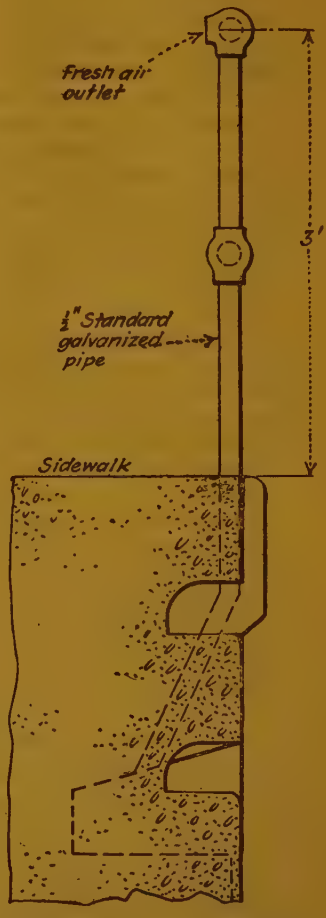


Fig 7. — Detail of handrail ventilation scheme.

U. S. Bureau of Mines and the engineering experiment station of the University of Illinois. With the data on exhaust gases of motor vehicles and their effect on human beings as a basis, on model ducts of large sizes extensive tests were made of the frictional losses which would have to be overcome in moving large volumes of air through large concrete and metal ducts and elbows and

delivered at frequent intervals through flues of various sizes and shapes. The formulas developed, which are extremely complicated, are a distinct addition to engineering knowledge. Due acknowledgment is hereby given to the commission and to other engineers connected with the tests used in developing the formulas, which were used in the ventilation design of the estuary subway.

All work on the estuary subway has been under the supervision of George A. Posey, chief engineer, and Austin W. Earl, engineer of designs. The board of consulting engineers consisted of the late Clifford M. Holland, Prof. William H. Burr of New York City and Prof. Charles Derleth, Jr. Since the death of Mr. Holland, Ole Singstad has been appointed to succeed him on the board. The author wishes to make acknowledgment here of assistance received from A. C. Davis, mechanical and ventilation engineer of the Holland Tunnel.

[656 .211.4]

Unification of railway passenger terminals,

By E. E. R. TRATMAN,
WESTERN EDITOR, « ENGINEERING NEWS-RECORD ».

Figs. 1 and 2, p. 615.

(*Engineering News-Record.*)

A combined railway and municipal problem which is present or impending in a number of cities is that of new or improved passenger terminals, and a proposition which may develop in many such cases is the unification of these terminals. In other words, it is the problem of the concentration of all traffic in one station instead of having it divided between two or more stations serving individual railways or groups of railways. Where a new city is planned in open country, as was the case with the still unfinished governmental capital cities of Delhi, in India, and Canberra, in Australia, it is easy to lay out railway lines and a union station in harmony with the city plan. Such design of a unit terminal, unhampered by existing conditions or occupancy, is a rather fascinating subject, but opportunities of this kind are extremely rare.

As a rule, the problem involves established terminals and various limiting conditions, and its solution means the altering or rebuilding of some existing lines in order to bring them all to one common focus at a single union or unit station. This station may occupy one of the existing sites or an entirely new site. Railway property thus set free may be developed for other railway purposes or it may be sold or transferred for municipal or private use. To effect unit operation economically under these circumstances can be no easy task. That it has been accomplished in some cases is not a strong argument in proposed cases, since every project presents its own problems.

What is unification. — As related to passenger traffic the term « unification » implies the accommodation of all the railways of a city within one union station under a single management. In this respect it differs from the unification of freight terminals, since no one station could handle the combined freight business of all the railways. The unification of freight terminals, therefore, implies the operation of all freight facilities as a multiple-unit system under one management, as discussed in *Engineering News-Record* of 4 March 1926, p. 354. The confusing of this distinc-

tion between the unification of passenger terminals and of freight terminals has led sometimes to the suggestion of impracticable plans or conditions.

Since the railway system centering at any city is formed usually by the independent growth of different lines, it is not easy to combine and connect the various main lines into a unified system with one central point or station. The difficulties will increase with the number of roads involved. They will be aggravated also where the topography is hilly or irregular and the railway lines are at different elevations.

The phrase « terminal » does not mean necessarily a dead-end railway terminus. It includes all large passenger stations through which trains may pass but which are terminal points for certain trains or divisions. Thus, the present discussion applies to the through stations at Indianapolis and Kansas City, as well as to the stub or dead-end stations at Chicago or New York. In fact, many stations comprise both stub and through features, as the Union Station at St. Paul and the Pennsylvania Railroad Station at Pittsburgh.

Analyzing the problem. — Under the various interlocking and conflicting conditions involved, the fundamental question in any individual problem of unification is : What will be its cost and its practical and economic advantages ? To this question no general answer can be given. Each case is a problem in itself, with its own limitations and its own factors as to location, traffic and civic conditions. While no one case is a criterion for another, any one case presents lessons in what to do and what to avoid.

Solution of any individual problem involves many aspects, both practical and economic, and from both the railway and the municipal points of view. Among these innumerable factors are : 1. adequacy of present stations; 2. advantages and disadvantages of proposed union station site; 3. present and prospective railway and city traffic conditions; 4. practicability of rerouting traffic or building new connecting lines; 5. cost of station, approaches and auxiliary works; 6. convenience of the traveling public; 7. character of railway traffic, or the proportions of through and local passengers; 8. relations of the several railways as competitive or connecting roads; 9. the progressive or backward attitude of the city in matters of municipal affairs and improvements.

One of the minor factors in a comparison of unit and independent stations is that of the relation of interstation traffic to the ordinary street traffic. A recent survey at Chicago showed that with nearly 30 000 persons arriving daily by 23 railroads at six terminals, about 4 000 are transferred from one station to another by a concern operating 106 motor buses for this service. No record is given of the number employing taxicabs for such transfer.

Station examples and comparisons.

Chicago and St. Louis. — As an example of the multi-station situation consider Chicago, with six terminals for its 23 railroads, exclusive of belt and local lines. Two of these stations are modern, while authority has been given for replacing a third on a grand scale. Several rival projects provide for eliminating the other three entirely or replacing them by one new station to serve some or all of the several lines concerned. With this situation, the establishment of a single union station appears to be economically and practically impossible. Equally impossible would seem to be the conversion of the complicated network of railways in and around the city into a unified system. Not that such union station schemes have never been proposed. As a matter of fact several such propositions are on record. One curious plan provided what might be called a multiple-unit terminal, composed of a series of adjacent stations placed end to end and having a series of loop tracks. Although Chicago is on level ground, any unification project would face the problem of lines at different levels, since two of the stations have their tracks elevated, two have them depressed and two have them at street level.

As an example of the single or unit station situation, consider St. Louis, with 20 main line railroads all served conveniently in one union

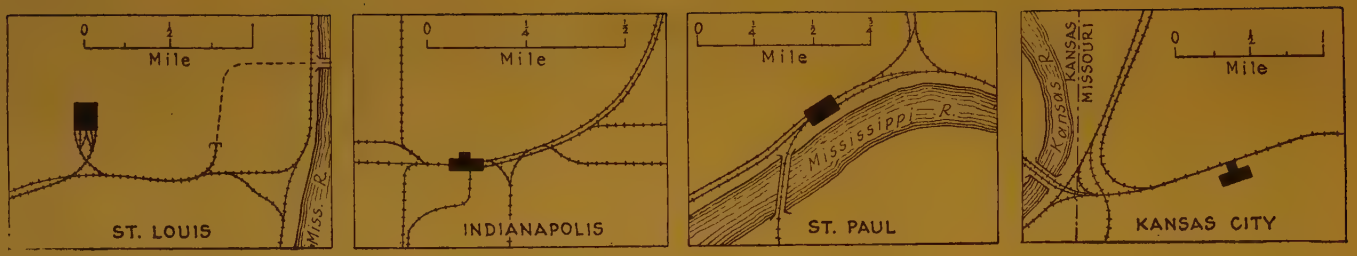


Fig. 1. — Cities having one main railway station.

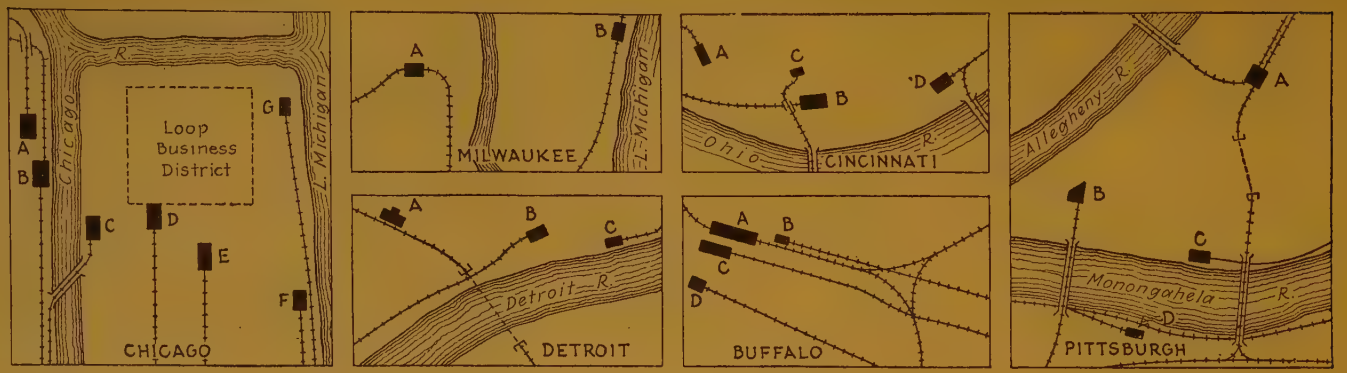


Fig. 2. — Cities having several main railway stations.

(Not drawn to scale.)

CHICAGO : **A,** Chicago & Northwestern Railway; **B,** Union Station; **C,** Grand Central Station; **D,** La Salle Station; **E,** Dearborn Station; **F,** Illinois Central Railroad; **G,** Illinois Central suburban terminal.

MILWAUKEE : **A,** Union Station; **B,** Chicago & Northwestern Railroad.

DETROIT : **A,** Michigan Central Railroad; **B,** Fort St. Union Station, **C,** Grand Trunk Western Railway.

CINCINNATI : **A,** Baltimore & Ohio Railroad; **B,** Central Union Station; **C,** Chesapeake & Ohio Railroad; **D,** Pennsylvania Railroad and Louisville & Nashville Railroad.

BUFFALO : **A,** Union Station; **B,** Erie Railroad; **C,** Lehigh Valley Railroad; **D,** Delaware, Lackawanna & Western Railroad.

PITTSBURGH : **A,** Pennsylvania Railroad; **B,** Pittsburgh & West Virginia Railroad; **C,** Baltimore & Ohio Railroad; **D,** Pittsburgh & Lake Erie Railroad.

station. But this station was built some 35 years ago, when the railway situation and the station environment were much simpler than they are now. As a result of broad vision in the first place and of improvements from time to time, the St. Louis station is still adequate for the service required. Whether effective co-operation of the Chicago railroads could have been secured in the same way 20 or 30 years ago, and whether a common station adequate for a long period of years could have been built at that time are questions of speculative interest only.

Unit and independent stations.

Conspicuous examples of large cities in which a single union station accommodates all the railroads are St. Louis, St. Paul, Kansas City, Indianapolis and Dallas, Texas. Examples of large cities having two or more main stations are Chicago, Boston, New York, Philadelphia, Buffalo, Detroit and Memphis. Particulars of the station conditions in a number of cities are given in the accompanying tables. Both Omaha and Seattle have two stations side by side, and different plans for the combination of all traffic in one station have been made, but have failed to meet approval of the railways.

At Cleveland, definite plans were made some years ago for a unit station on the lake front, forming one of a group of public buildings at a civic center. The other buildings were erected, but the station project was upset by a rival project for a station in the business section of the city. The latter is now being built, but will not be used by all the railways, so that there will be at least two main stations. It seems unfortunate that the original plan could not have been carried out, as the location was convenient and the building would have been a distinctive feature of the civic center.

Situations analogous to these at Omaha and Seattle are presented by Lincoln, Neb., and Springfield, Ill. At Lincoln, five trunk lines using three old stations could not agree upon plans for a revision of lines and a union station. As a result, one road is erecting for its own use a new station on the old site, and the railway situation remains unchanged. At Springfield, three railways pass through the city at street level and have their own stations. For some time the city has been trying to have these conditions improved, but the railways have not agreed to any of the plans suggested. With this station project is involved that of grade separation, which must be effected eventually.

That union stations are practicable at small as well as large cities is illustrated by Vincennes, Ind., which has one station serving all the four railways.

TABLE I.

Typical cities having one railway station.

CITIES.	Number of railroads.	Population.
Augusta, Ga.	6	55 700
Dallas, Texas.	8	200 000
Galveston, Texas. . . .	5	49 100
Indianapolis, Ind. . .	6	367 000
Jacksonville, Fla. . .	5	96 500
Kansas City, Mo. . .	13	375 000
Portland, Ore.	5	260 000
St. Louis, Mo.	20	830 000
St. Paul, Minn.	9	248 000
Texarkana, Ark. . . .	4	10 050
Vincennes, Ind. . . .	4	18 000
Washington, D. C. .	5	528 000

Broadly speaking, railroads are not favorably disposed towards union station projects. Apart from physical, operating, financial and co-operative difficulties among themselves, one strong reason for this attitude is a tendency of municipal authorities to overload such a project with street and other local improvements and to impose an excessive amount of work and expense upon the railroads. These improvements are of benefit mainly to the citizens and its street transportation, while they do not bring revenue to the railroads. Active co-operation between the railways and the city

is essential to a successful general plan, but too often a political element is introduced and the project ceases to be regarded on its merits as a business proposition. This is probably one reason why the railways sometimes object to features which on their face appear reasonable requirements.

Railway traffic conditions.

It might appear that if St. Louis can accommodate 20 railroads in one station, Chicago might do the same for its 23 railroads. There is an essential difference, however, in the traffic conditions of the two cities. At Chicago the railways have an enormous suburban traffic, while at St. Louis this traffic is small. Thus, three of the Chicago stations aggregate about 450 suburban trains daily, while the St. Louis station have also an aggregate of 270 main-line trains daily, as against 222 at St. Louis.

It has been claimed that no such heavy suburban traffic as that of Chicago could be operated satisfactorily at one station, in addition to the main line trains. But at New York, the Pennsylvania Railroad station is credited with 394 suburban trains and 164 main-line trains daily, while the Grand Central station has 240 and 190 respectively. Here again there are vital differences in local conditions. These two stations serve three railroads only, and have not the ramified approach lines under divided ownership which complicate the situation at St. Louis and especially at Chicago.

TABLE II.

Some cities with more than one railway station.

CITIES.	Number of railroads.	Number of stations.	Railroads per station.	Population.
Atlanta, Ga.	8	2	3 and 5	203 500
Boston, Mass.	3	2	1 and 2	787 000
Buffalo, N. Y.	11	4	1 to 3	544 000
Chicago, Ill.	23	6	1 to 7	3 048 000
Cincinnati, Ohio	10	4	1 to 6	411 000
Cleveland, Ohio	7	5	1 to 3	960 000
Columbus, Ohio	6	2	1 and 5	285 000
Denver, Colo.	7	2	1 and 6	285 000
Des Moines, Iowa	8	4	1 to 4	146 000
Detroit, Mich.	8	4	1 to 3	1 290 000
Houston, Texas	7	3	1 to 5	138 000
Los Angeles, Calif.	4	2	1 and 3	576 000
Louisville, Ky.	9	2	5 and 4	311 000
Memphis, Tenn.	8	2	3 and 5	177 000
Milwaukee, Wis.	3	2	1 and 2	517 000
Minneapolis, Minn.	9	2	3 and 6	434 000
Mobile, Ala.	4	3	1 to 2	66 800
New Orleans, La.	11	6	1 to 4	419 000
Norfolk, Va.	8	5	1 to 3	174 000
Oklahoma City, Okla.	6	3	1 to 3	100 000
Omaha, Neb.	9	2	1 and 8	215 400
Philadelphia, Pa.	3	3	1	2 008 000
Pittsburgh, Pa.	5	4	1 and 2	637 000
Savannah, Ga.	5	3	1 to 3	95 000
Seattle, Wash.	5	3	1 to 2	320 000
Tacoma, Wash.	4	2	1 and 3	106 000
Terre Haute, Ind.	5	2	2 and 3	72 000
Toledo, Ohio	12	4	1 to 9	294 000

At the lower end of the traffic scale are the Central Union station at Cincinnati, with 147 main-line and 12 suburban trains; and one of the four Buffalo stations with 31 and 14 respectively. At Kansas City, the one station has 216 main-line trains, but no suburban trains. One of the Chicago main-line terminals is peculiar in that it handles no surburban trains, for although the railroad has a very heavy suburban business it handles this at a separate terminal. Another feature in traffic conditions is where two or more stations in a city have only light traffic. In such cases, it may be well for the railways to consider the possible economics and advantages resulting from a single union station, with its facilities and staff, in place of scattered stations which are empty and idle for a large part of the time.

Unit station management.

A union station is managed, as a rule, by a company or organization representing some or all of the railroads using it, any railroads not included in the joint ownership being accommodated as tenants. Less frequently the station is owned and operated by one of the railroads, with all the others as tenants. Of 37 union passenger stations listed in the reports of the yards and terminals committee of the American Railway Engineering Association, 24 have joint ownership. These 24 stations serve two to seven railroads each, while one of those owned by a single railroad has seven tenant railroads.

Two features in which unit or union stations differ materially and which affect the control of station traffic are : 1. arrangement of the approach lines, and 2. equipment service rendered to the railways. As to the first, and referring to the plans in figure 1, compare the Kansas City station with its easy direct approach lines, and the numerous junctions and connections close to the stations at Indianapolis and St. Paul. As to service conditions, some union station organizations do nothing in the way of switching or making up trains, storing and cleaning passenger cars, or caring for locomotives of the several railways, although if the station has its own switching engines it will take care of these. At other similar stations these functions are provided for the railroads to a greater or less extent, sometimes on a comprehensive scale.

Conclusions. — While the unit station plan in principle presents certain advantages to the railroads, the city and the traveling public, there are so many difficulties and objections and limiting conditions as to preclude any recommendation of general applicability. Each case is distinctly a problem in itself, and its solution depends largely upon personal attitudes and the existence or absence of co-operation, probably quite as much as upon the physical aspects of the problem. This active co-operation, to be effective, must include not only the railways among themselves, but the railways in conjunction with municipal authorities, commercial and civic associations, and local public opinion. It is evident from what has been said that the single unit station can be and has been applied to large and small cities. The main part, then, in considering any individual project, lies in an analysis of the practical and economic aspects of that particular case.

MISCELLANEOUS INFORMATION

[621 .33 (.485)]

1. — The Stockholm-Göteborg electrification.

Figs. 1 to 5, pp. 620 to 622.

(*Railway Age.*)

Electrification of the Swedish Government line from Stockholm to Göteborg, a distance of 285 miles, has been completed. Sixty-eight miles of the line is double track and 217 miles is single track. Running time of express passenger trains from Stockholm to Göteborg has been reduced from nine to seven hours. The work was sanctioned by the Swedish Parliament in 1920, and at that time the problems given special consideration were the kind and the source of power and inductive interference with communication circuits. These questions were studied by a special committee which made its report in 1923, when the work of electrification was started. Single-phase, 16 000-volt, 16 2/3-cycle power is used and communication circuits are placed in trenches along the right-of-way.

Inductive Interference.

In the case of the electrification of the Northern Railway in Sweden, telegraph and telephone lines were moved to avoid disturbances, a precaution which increased line maintenance difficulties. In view of recent improvements in cable design, the telephone, and in some instances the telegraph circuits, have been placed underground between Stockholm and Göteborg.

Two cables have been installed, one for the railroad communication service, laid along the railroad, and a second for the Telegraph Administration's long-distance circuits. The latter, however, were placed along the country roads as far from the railway as could be justified by economic considerations. It has not been found feasible to place all of the Telegraph Administration lines in cable along the railway. Thus, there are open-wire interurban and subscriber's lines, which, as far as practicable, have been moved away from the railway line. Some of the Telegraph Administration lines, used almost entirely for transit traffic between Stockholm and Göteborg, still consist of open wire circuits, which, however, are a considerable distance from the railway.

These precautions do not eliminate disturbances due to induction from the current in the trolley circuit. To counteract these it has been found necessary to introduce a balancing circuit, which consists of a return wire, carried on the poles which support the trolley circuit, this wire being connected to the rail at intervals of 1.7 miles. In some instances (in the neighborhood of the larger converter stations) this distance has been reduced to 1.35 miles. At points approximately midway between these intervals, so-called feeder booster transformers are installed, their function being to force the current, which flows from the locomotive, through the rails, back through the return wire.

To obtain the desired result it has been found necessary carefully to adjust the position of the return wire with respect to the trolley circuit. Considerable difficulty was experienced in the stations in this respect on account of the extensive over-head contact network. It has been possible by the use of a special by-pass circuit for the trolley current at the stations, to arrange the return path of the current so that the induction from the trolley circuit is prevented. Incidentally, this arrangement affords certain operating advantages.

The above mentioned arrangements for the elimination of disturbances have, so far as can be ascertained, proved entirely satisfactory

Fig. 1. — Map of district between Stockholm and Göteborg.

Fig. 2. — Type of overhead construction on single track line.

on the Stockholm—Göteborg line. By careful adjustement of the position of the return wire the disturbing voltage has been entirely eliminated in the long-distance cable between Stockholm and Göteborg, while the corresponding voltage in the railway communication cable, laid along the roadbed, has been reduced to less than one-half per cent of its original value.

An American trenching machine was used to accelerate the laying of the telephone and telegraph cables in the roadbed. This machine, drawn by a heavy steam locomotive, dug the required trench all the way from Stockholm to Göteborg and the work of laying the cable over the entire 285 miles of line was completed in six months' time.

Fig. 3. — The trenching machine.

Power supply.

Single-phase current for the Stockholm-Göteborg line is taken from the existing widespread national system, which has been extended at the major power stations : Alvkarleby, Västerås, Motala and Trollhättan. The main lines inter-connect these power stations by special arrangement, which enables power to be taken from one or the other, as required, for the railway supply. This insures a constant current supply from a network which need never fail due to a temporary breakdown in a power station.

The current supply to the railway is brought in at Södertälje, Sköldinge, Hallsberg, Moholm and Alingsås. Substations have been erected at these places, where the three-phase supply is transformed by means of rotary converters to the low-frequency single-phase, 16 000-volt supply required. The distance between the converter stations has been made as great as 78 miles.

Trolley wires have been placed above all line and station tracks, where locomotives will pass; the required changes have been made in the telegraph and telephone lines running near the railway and the first 50 electric locomotives have been procured.

The work on the electrification was started in the summer of 1923, Parliament having approved the revised plans of the Railway Administration. It required nearly a year to survey and mark positions for the electric lines,

Fig. 4. — A section of double-track line showing houses for booster transformers.

Fig. 5. — A nine-car passenger train.

to plan in detail the buildings and to order the electric locomotives and accessories required. During 1924 work began on erecting poles, laying telegraph and telephone cables and the building of the converter stations. While this work progressed the electric locomotives and apparatus for the converter stations were being made.

Overhead system.

The trolley line construction is of the so-called « Z » type, which was used on the Northern Railway. The trolley wires are arranged on iron tube supports, hinged at the insulators, and are equipped with an automatic device for regulating the tension so as to keep it constant; also thereby providing a practically horizontal contact wire at all temperatures. Some improvements have been incorporated, particularly in regard to the section points and in the arrangements for switching in and out of the track transformers.

A heavy copper conductor is carried on the poles which support the catenary and contact wire. This conductor is mounted on insulators at about the same height as the contact wire. It carries the return current and also acts as the compensating line in respect to the trolley circuit.

Another two-wire circuit is carried on insulators on the top of the trolley poles. This circuit carries current for lighting, small power supply and signalling for stations, station yards and other faclities along the line.

The trolley circuit is divided into 12 independent main sections which are fed directly from the converter stations. Södertälje and Alingsås each supply power to three sections, while the remaining three converter stations feed two sections each. The converter stations operate entirely independently of each other and their line networks are separated by so-called *dead* sections in the trolley system. The electric locomotives coast over the *dead* sections.

Locomotives.

The express and passenger trains on the Stockholm-Göteborg line require locomotives with speeds up to 56 miles an hour, when pulling trains weighing 550 tons. Likewise, for freight trains weighing 1 000 tons locomotives with speeds up to 44 miles an hour are required. The weight of the locomotive is not included in the above figures. The types of locomotive adopted are identical in external appearance, each being provided with three driving axles and two guiding axles, one at the front and one at the rear.

Each locomotive weighs 88 tons, with 56.3 tons on drivers, and is equipped with two motors aggregating 1 700 H. P. The series type alternating current motors are gear connected to a single jack shaft mounted in the frame, level with the driving axles. Side rods transmit the power from the jack shaft gears to the driving wheels. By changing gears a passenger locomotive can be converted for freight service and conversely. About two days' time is required to make this change.

The central part of the locomotive cab houses the motors, switch gear, blowers, air compressor and the transformer used to convert the 16 000-volt supply to voltages varying from 24 to 1 000. These different voltages are used for controlling the speed of the driving motors for lighting, heating and for auxiliary motors. The locomotives are designed for double-end operation and there is a control compartment at each end.

The total cost of the electrification at the present rates of exchange was in round figures $11 000 000, which represents a cost of $38 600 per mile of electrified road. The cost is made up about as follows :

Converter stations	$ 1 200 000
Trolley wires, etc.	4 100 000
Cables and removal of telegraph and telephone lines	2 900 000
Locomotives	2 900 000

[628 .13 (.431) & 691 (.431)]

2. — Construction of an under-river tunnel under a continuous reinforced concrete raft. The Metropolitan Electric Railway of Berlin under the Spree.

Figs. 6 to 12, pp. 625 to 627.

(*Génie Civil.*)

The underground lines of the Metropolitan Electric Railway of Berlin have been extended gradually since it was first opened in 1901 (1) and are carried under the Spree at several points in shallow tunnels under the bed of the river. These tunnels are rectangular in section, and the lining is in reinforced concrete (2). As the water above the tunnels is shallow [about 4 m. (13 feet)] they were easy to build without using compressed air, by excavating inside the limits of a temporary dam and then erecting the concrete walls in the trench. The work was done in steps so that most of the river was left free to navigation. Water from the Spree was pumped out direct and that from the sub-soil was taken care of by drainage sumps. The last section, built during the war, uniting the suburban district of Gesundbrunnen, to the north of Berlin, with that of Neukölln, to the south east, 9.5 km. (5.9 miles) in length, 8 km. (5 miles) underground, runs under the Spree near the Jannowitz Bridge (figs. 6 and 7). At this point the tunnel was built in the novel way described below, because of its interest to engineers who may have to design tunnels to be carried at moderate depths under rivers.

First of all a shallow trench 1 m. 50 (4 ft. 11 in.) deep was dredged on the line of the tunnel (fig. 8) across the bed of the river. Along the line of the side walls of the tunnel two lines of piles *p* were driven, and two lines of drainage tubes *t* to collect the sub-soil water were bored. The dredging, driving of the Larssen type jointed piles, and the boring of the tubes at the same time was the first phase of the work.

During the second stage (fig. 9) a number of steel lattice girders, set at right angles to the axis of the tunnel, were placed in the dredged channel, after which the concrete was run in. In this way the very large water-tight raft D, in concrete reinforced by the girders was obtained. The girders were arranged on floats and then sunk to the bottom, care being taken to ensure that they were supported on the heads of the piles, reversed longitudinal gutters to ensure tight joints being inserted between them.

These gutters shewn at *a* and *b*, figures 9 to 12, tie the girders together longitudinally, and were packed with plastic material which the weight of the steel reinforcement squashed down on to the heads of the piles. The lowering of the girders was checked by divers who took care to see that the ends of the guttering overlapped properly without gaps between the packing to prevent all risk of water entering through these joints. The method was entirely satisfactory.

The concreting of the raft D was then carried out by pouring the concrete under water, after which a protective layer of gravel 20 cm. (8 inches) thick was spread over it.

The concrete raft, which extended without a break from one side of the Spree to the other, was given several months to set. The tunnelling itself was then taken in hand by opening out the excavation at each down slope (fig. 10), and by coupling the tubes *t*, until then fitted with protecting covers to pipes *c* connected to the pumps for lowering the level of the underground water below the invert of the tunnel.

The maximum quantity pumped reached

(1) A description of the original system is given in the *Génie Civil*, 22 March 1902 (vol. XL, No. 21) and the extensions in the number of the 7 February 1914) (vol. LXIV, No. 15, p. 292).

(2) See the article mentioned above in the 7 February 1914 number.

40 m³ (1 412 cubic feet) a minute. The ground was then sufficiently dry to be excavated by pick and shovel. The level was carried down to the tunnel mean level 24 m. (78 ft. 9 in.) and after concreting the invert the side walls were completed, the piles and tubes being left in the ground (fig. 11). Figure 12 is a section through the finished tunnel and shews the continuous wall, also in reinforced concrete, which separates the two lines and stiffens the tunnel.

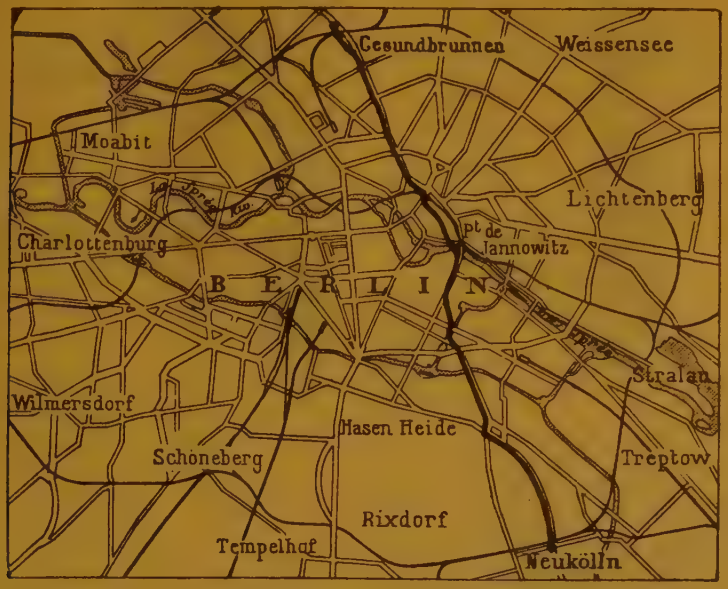


Fig. 6. — Plan of Berlin shewing the North-South Metropolitan line.

For clearness the other lines are not shewn.

Fig. 7. — Plan shewing the North-South line carried under the Spree.

The raft D forms the principal part of the roof, and is reinforced by the thinner liner completed towards the end of the undertaking.

The tunnel itself is 172 m. (564 feet) long; with the approaches having gradients of 3 and 4 %, the total length is 486 m. (1 594 feet). The mean rail level is 8 m. 90 (29 ft. 2 in.) below the mean water level of the Spree.

The work took a year to complete and was carried out by Messrs. Siemens-Bauunion. This Company has also made use of this method of construction for shorter tunnels (67 m. [219 ft. 9 in.] and 30 m. [98 ft. 5 in.] under-river length, excluding approaches).

Several years' experience has demonstrated the reliability of this method, which is very simple in principle, and relatively cheap when compared with the sunk caissons or tunnelling

Figs. 8 to 12. — Succeeding phases of the work of building the tunnel under the Spree beneath a reinforced concrete raft.

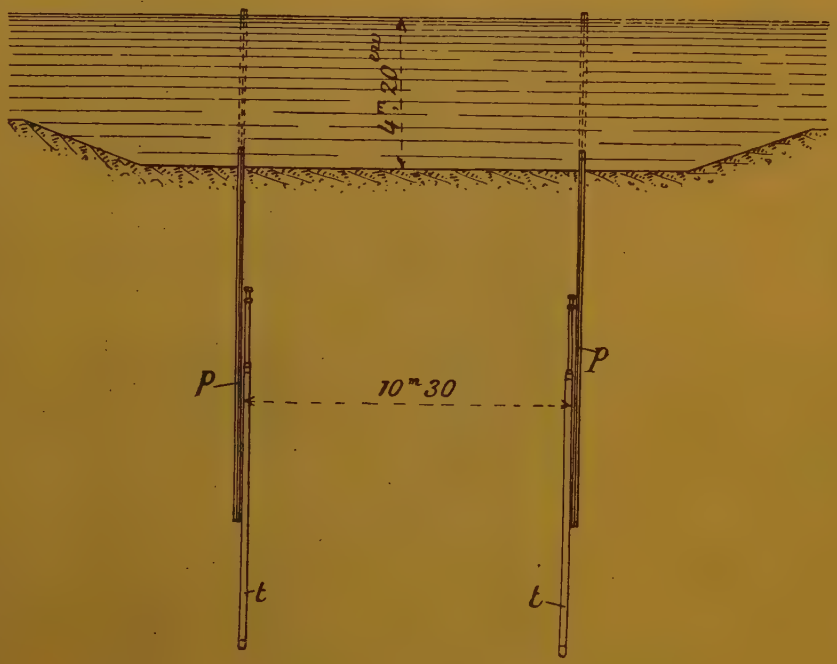
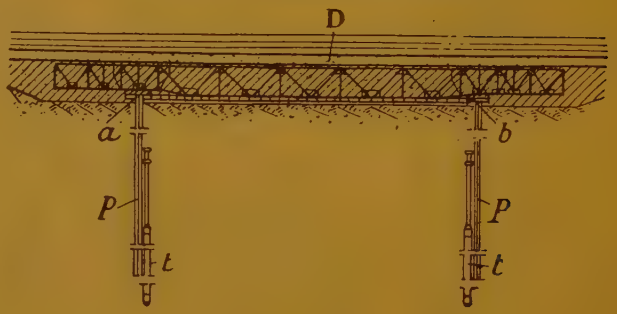


Fig. 8. — Driving of piles and boring of draining tubes.

Fig. 9. — Execution of raft D.



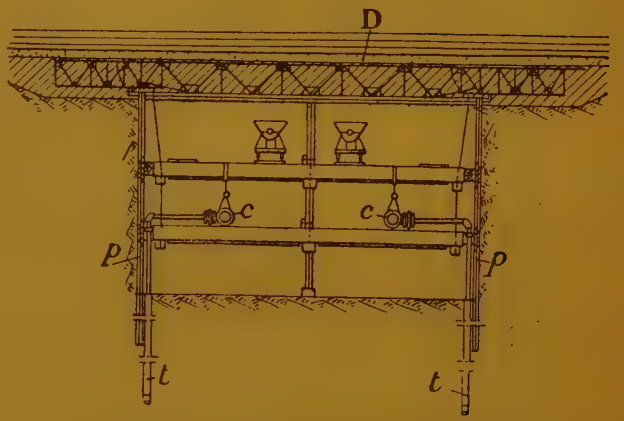


Fig. 10. — Excavation under the raft.

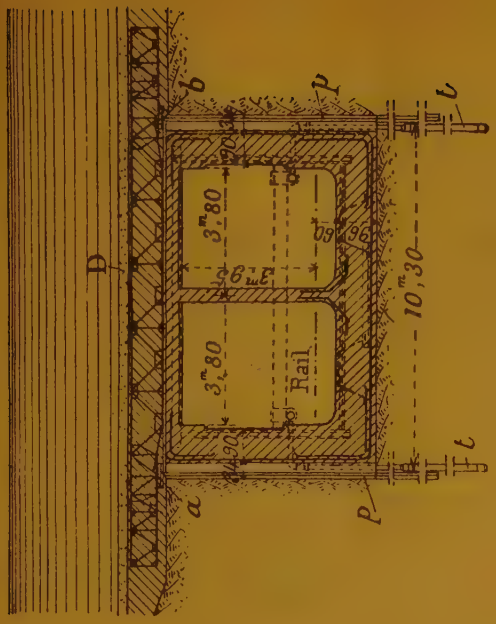


Fig. 12. — Section through finished tunnel.

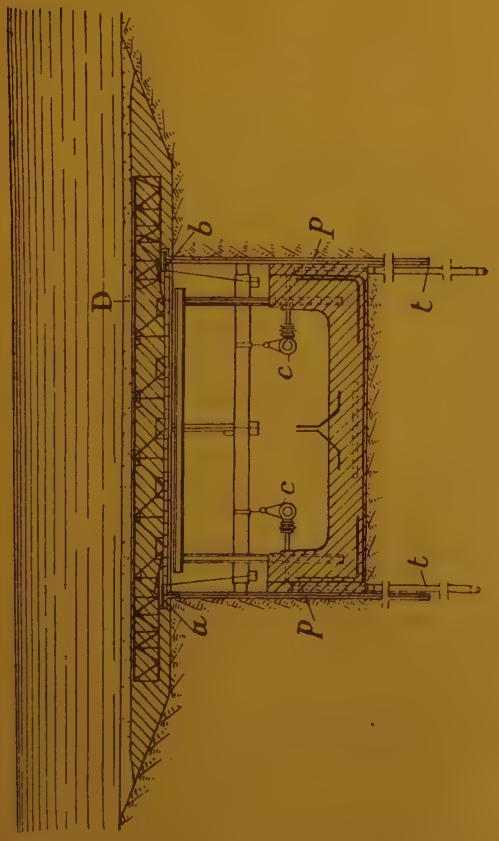


Fig. 11. — Concreting tunnel.

shields used previously, notably in Paris when carrying the Metropolitan under the Seine.

A. C.

[625 .214]

3. — Axleboxes with S. K. F. roller bearings for railway vehicles.

Figs. 13 to 17, pp. 628 to 630.

(*Revue générale des Chemins de fer.*)

Axleboxes on the roller bearing principle, made in particular by the S. K. F. (1) Ball Bearing Company have been tested by a large number of railways. The design is based on the use of roller bearings through which the load is transferred to the journal and the rubbing of the brasses eliminated. The present position with regard to the use of these bearings will be briefly considered by reviewing the applications that have been made already.

Bearings in use. — In France about 60 carriages in all have been fitted up by the Eastern, Orleans, and Paris, Lyons and Mediterranean Companies. The State Railways are also carrying out tests on suburban electric stock.

The Swedish State Railways were the first to use these bearings and now have about 6 000 S. K. F. bearings in use, most of them being under 600 mineral wagons and 250 bogie carriages.

One American Company, as the result of trials carried out some time ago, have fitted them to 180 heavy bogie carriages.

The German Railways have also fitted about the same number.

The Danish State Railways have fitted 90 carriages, and Tchecho-Slovakian Railways have nearly as many as the French Companies. Several other foreign Companies have also started to fit them.

Test of ball bearing boxes. — Adoption of roller bearings. — In consequence of the number of hot bearings with ordinary oil boxes,

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(1) These are the initials of *Svenska Kullager Fabriken* of Gothenburg (Sweden).

the Swedish Railways carried out tests in 1915 with *ball bearing* boxes on 50 six-wheeled wagons weighing 45 t. when loaded. The wagons so fitted shewed the following improvements : complete absence of heating, considerable saving in oil, and appreciable reduction in tractive resistance.

The tests shewed however that the surfaces on which the balls rolled, even when of the highest quality and properly supported by the grooves in which they roll, were too weak for the loads usual with railway stock. As the parts had to be replaced too frequently, tests were made with accelerometers to determine the value both of the vertical and lateral shocks which seemed to have considerable effect. The investigation shewed that the required load capacity was greater than that which could be obtained if balls were used.

The S. K. F. Company then commenced a thorough investigation into *roller bearings* suitable for this service.

Description of S. K. F. roller bearing axle-boxes. — A modern bearing consists of the following parts (fig. 13) :

An outer race held in place in the box by pressure;

Fig. 13.

An inner race secured to the journal;

A set of rollers between the free faces of the races;

A cage with wings which rest on the rollers and prevent them from rubbing against one another.

The type of S. K. F. bearing developed especially for railway purposes has two rows of rollers. The rollers, instead of being truly cylindrical, are slightly curved : they conform to the profile of the two channels cut in the inner ring. These grooves are not parallel, but are inclined symmetrically with relation to the main axis of rotation : this arrangement allows the outer race to be given a spherically curved face forming a spherical bearing and distributing the load properly.

The rollers have another peculiar feature : they are slightly tapered off with the larger end towards the inside of the bearing. Under load they get an end bearing against the centre shoulder of the inner race : and as both faces of this shoulder are spherical, following exactly the shape of the large end of the rollers, the rollers are guided properly, and there is no play. Figure 14 shews the arrangement of the different faces.

The method used to guide the rollers is of the greatest importance if the bearing is to work properly. The older designs, both with straight rollers and long rollers, failed for this reason. It is impossible to make long rollers mathematically cylindrical, and if there is any coning the rollers tend to get out of square. They wear mostly at the centre of their length (like an hour glass) and soon get out of line. A moderately hard end blow is then sufficient to increase the obliquity sufficiently to cause flats on the rollers, which then have to be taken out of use.

With the spherical construction the bearing will stand up to any end shock transmitted by one or other side of the shoulder of the inner race. The cages can also be made in brass without rivets with the wings open on the outer side, so that once the bearing is assembled it can be removed and all its parts examined. The above bearings are used in different ways according to the Railway Company. The Swedish State Railways use as a

rule boxes guided by the horns alone, and fit *two roller bearings in each journal* so as to get a rigid box. In the first boxes, the rollers in the race nearer the wheel were rather short and were guided by the edges of the groove in the inner ring. The outer ring alone was spherical and therefore took all lateral thrusts, as well as part of the vertical loading. The two

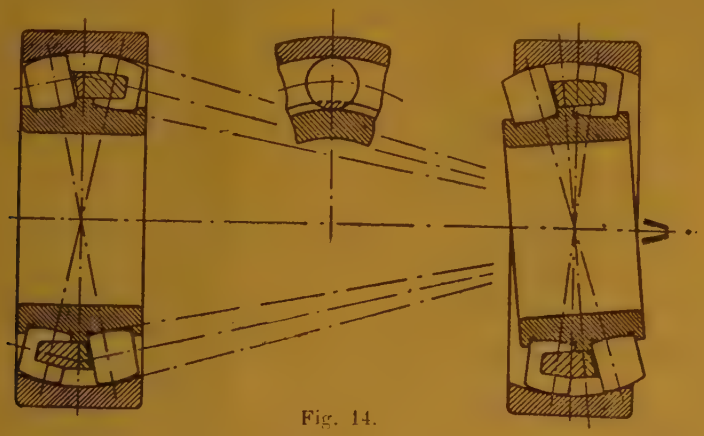

Fig. 14.

bearings were separated by a distance piece protected by a stepped dust shield, and were pulled up solid against the journal collar by a large nut or by three strong set screws in the end of the journal.

A similar arrangement was used by the French lines and by most of the European Companies. In France preference was given to the use of two spherical bearings which naturally reduce the load on the rollers by increasing the number of bearing points.

A useful improvement now standardised was to provide means for taking up any play when tightening up the roller races (figs. 15 and 16). The inner ring is bored out conically and slightly larger than the journal, which is cylindrical. Between these two parts a removable split sleeve, which consequently can be expanded, is forced into place by a nut at the end, and ensures a good seat between the ring and the journal. The end of the sleeve is screwed with a different thread to take a special nut, which by acting on the side of the inner bearing withdraws the sleeve, when the complete bearing can be removed *as a whole*.

This assembly has the following important advantages :

1. The bearings are thoroughly well secured and play can be taken up;

2. The journals do not require to be machined with extreme accuracy;

3. The tyres can be re-turned in ordinary wheel lathes;

4. Journals can be more easily examined;

5. The bearings are assembled cold.

When two bearings per journal are used, the demountable sleeves take the place of the distance pieces of the earlier design. The journal is sometimes reduced in size below that of the old design, but as there is no wear or friction on it, it can be allowed to work under rather higher stresses than ordinary journals.

In other types of boxes *only one roller bearing is used*. The boxes of the American railway mentioned above were specially designed in this way. These boxes have a square extension which slides inside an opening of the same shape in the horn stay. The boxes are larger than when two bearings are used, but are shorter, which is always an advantage. The box itself is in one piece, and there are obviously fewer parts than in the previous design.

A box with a single roller bearing per journal is also very suitable for the diamond type truck. In these bogies the boxes are bolted in place after the frame has been assembled. The spherical bearing is a very suitable design as

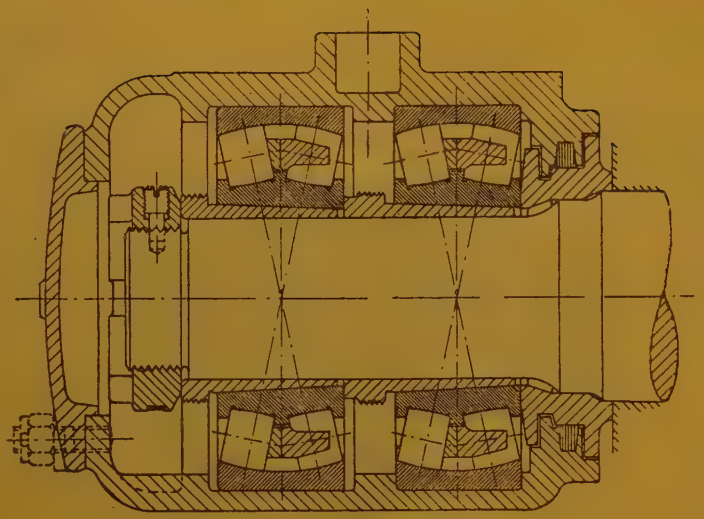

Fig. 15.

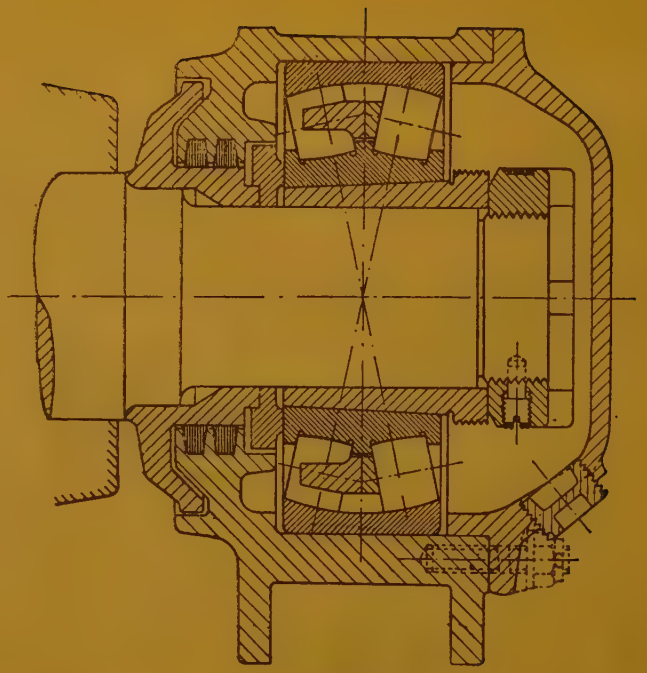

Fig. 16.

they are always in line in spite of the unavoidable differences of level between the two sides of the bogie. Single block brakes can also be used.

A later design of single roller bearing box is the one used in the new passenger coaches designed by the S. K. F. Company in collaboration with the Swedish Railway Work Shops Company. A stirrup is fitted underneath these boxes through which the load is applied, and in this way stable equilibrium about the centre of the spherical bearing is obtained. The journal is relatively speaking very short, and the centre line of the spring gear can be brought nearer to the wheel. The balancing lever is rectangular, and its ends engage in the stirrups of the boxes where they are properly locked in place.

The lever can be erected or taken down very easily. The height of the lever can be adjusted to suit the boxes and that of the spiral springs to suit the lever. The springs can also be adjusted separately and replaced if necessary with no other tools than an adjustable spanner. Figure 17 shews a general view of a bogie fitted with boxes of this kind.

Tests have been made with bogies of this type. A sleeping car of 44 t. weight fitted in 1925 with new bogies which had not been run in, was run the first day 60 kilometres (37 miles) at high speed (100 km. [62 miles] an hour) without it being thought necessary to give it a run at slow speed or gradually work it in any way. The bogies were then put into regular use, and nothing but favourable comments on their good riding and free running have been received.

Advantages of using roller bearing boxes. — 1. *Prevention of hot boxes.* — S. K. F. boxes do not run hot, and in America they have come to be called « no-hot boxes » in consequence. They are always ready for use without any preliminary running in even when new or after standing months under full load. With this arrangement no spare coaches are required to meet heating cases as has had to be done sometimes.

2. *Reduction in tractive resistance.* — Tests have proved that with roller bearing boxes there is a saving in tractive resistance which, in view of the cost of fuel or traction current, is of particular interest.

In France, on the Paris, Lyons and Mediterranean and the Paris-Orléans systems, tests were made with trains composed of 6 or 8 vehicles fitted with roller bearings, and an equal number fitted with ordinary bearings, and two dynamometer cars marshalled in the required positions. The results shewed a reduction in resistance of 13 % in favour of the roller bearings.

In Sweden two complete bogie trains, one with ordinary and one with roller bearings, were tested. The coal and water was measured for a period of 15 days over a certain section of line. The result was a saving of 5 kgr. of coal per 1 000 ton-kilometres (18 lb. per 1 000 English ton-miles) on a line with gradients up to 1 in 100. It must not be overlooked that the tractive resistance is a function of the longitudinal section of the line, and that, other factors being equal, the saving is less on steep than on easy gradients (the saving of 13 % given above was noted on the Paris, Lyons and Mediterranean between Paris and Montargis).

To quote the test results : a number of large self-discharging coal wagons were fitted with roller bearings at the beginning of 1923.

The tractive resistance in ordinary working was found to be 1.4 kgr. per t. (3.1 lb. per English ton) as compared with 2 kgr. (4.5 lb.) for the wagons with ordinary bearings.

It is well known that roller bearings are much better as regards starting resistance. Their use should be considered on the vehicles of different kinds of trains which have to make frequent stops and are heavily loaded.

The use of electric traction has enabled roller bearings to be applied to the driving axles. As the resistance to movement in kilograms per ton of an electric locomotive or a motor coach is much lower than that of a steam locomotive, there is relatively greater interest to improve the running of the trailers.

The results obtained in different countries have also shewn that the savings obtained with roller bearings can be made use of by

increasing the weight of the trains without changing the type of locomotive or increasing the fuel consumption.

3. *Reduction in upkeep.* — An S. K. F. box uses no oil : when erecting it, it should be filled with grease which should be renewed when the coach is shopped. A box filled with grease can be expected to run 100 000 kilometres (62 140 miles) without being touched owing to the efficient retainer fitted. Wagons ought to go three years before renewing the grease.

If the cost of a roller bearing box is high, the cost of repair is small as the roller bearings appear to have a very long life. For example, out of 600 bearings put in use in France about the same time, not a single part had to be renewed at the end of two years. In the United States of America all the bearings of the first test train were taken down and no wear was noticeable although they had run over 500 000 kilometres (310 700 miles). As the journals are not subjected to frictional wear, the diameters were as new, and neither the wheel seat shoulder nor the journal collar was worn.

[621 .9 (.42)]

4. — A new machine tool for locomotive shops.

Figs. 18 and 19, p. 633.

(*The Railway Gazette.*)

John Holroyd & Co. Ltd. have recently designed and built an interesting machine, illustrated hereafter, for boring crank-pin holes in locomotive wheels either straight or taper, and for turning and grinding crank pins at true quartered centres. The machine consists of two self-contained heads, carried on a strong base of box section, and the axle stays, which have fine vertical and radial adjustment by screws, and can be set at different positions on the baseplate for varying track gauges. Provision is made for locking the wheels securely while being machined.

The main body of the machine is of robust design, and the saddle is carried upon angular machined ways, the headstock being mounted upon the inclined ways of the saddle. The headstock carries the various attachments, and is adjustable on the inclined slide in order to grind crank pins of varying throws. After the head has been set to the correct crank throw to dead stop plates, it is securely locked to the traversing saddle. The main spindle is of cast iron revolving in gun-metal capped bearings, the end thrust being taken by a ball thrust washer. The front end of the spindle is prepared to receive the various heads, attachments, etc. The drive to the main spindle is from a constant speed motor, through pulleys and a change speed box with gearing on to the large diameter spur gear mounted on the spindle, three changes of speed being provided. The drive to the emery wheel on the grinding head attachment is obtained from the main drive motor through a belt drive and gearing on to the emery wheel spindle. The in-feed to the emery wheel is by hand, giving fine adjustment; quick adjustment is also provided. Automatic in-feed operating at the end of return stroke of the saddle can be provided if desired.

A specially notable feature is the patent automatic, reversing, adjustable feed which is provided for grinding up to a shoulder by dead stops, which makes an overrunning of the grinding wheel impossible. The automatic traverse of the saddle when grinding can easily be controlled by a foot lever in conjunction with a hand reverse lever; the foot lever cuts out the power operating of the automatic reverse motion. The change-over from the grinding feeds to the slow boring and turning feeds is controlled by lever conveniently placed with all the other principal controls in front of the machine.

The various motions are interlocked to prevent conflicting movements. Three changes of feed are provided for both grinding and boring, also hand traverse to the saddle.

The taper turning head is arranged with a

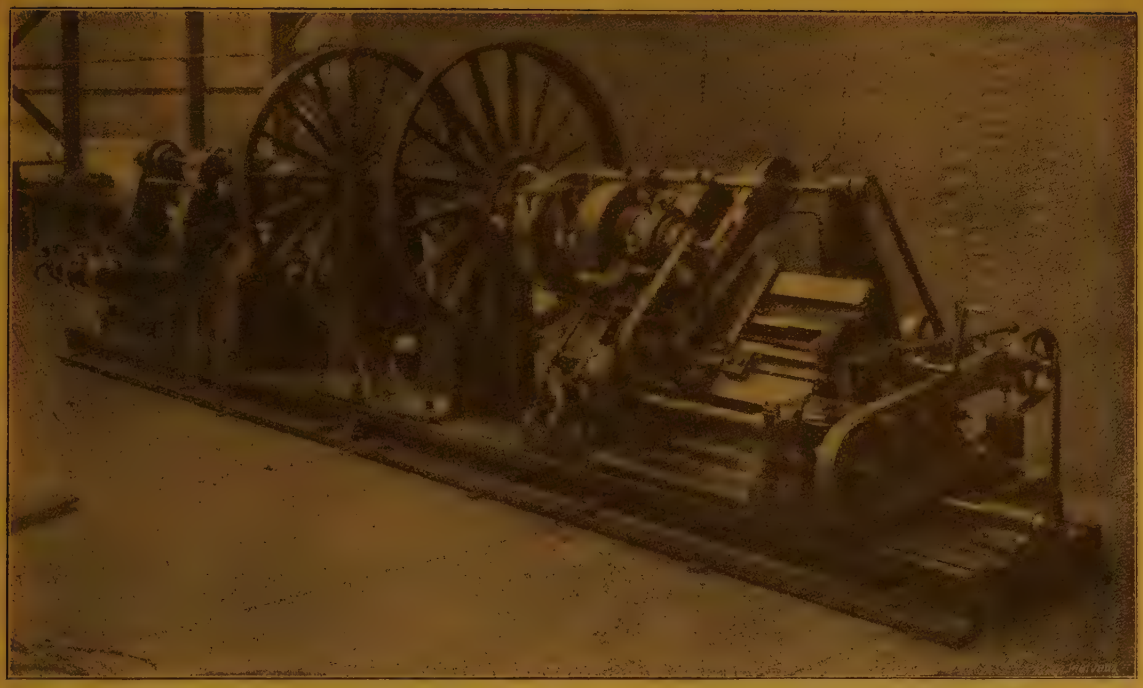

Fig. 18. — A specially-designed crank pin grinding and quartering machine.

Fig. 19. —Grinding attachment for finishing crank pins.

fixed taper, and the feed to the tool in this case is arranged in the head itself, being obtained by holding the countershaft in the main spindle stationary while the head revolves round it. Adjustment for depth of cut is provided. The parallel boring and turning head feed is obtained by the saddle traversing. Adjustment of the tool slide for depth of cut and varying diameters is provided and is operated by a hand wheel and screw. Attachments for bolting to the spindle flange can be supplied for receiving centres and drills, etc. The machine will drill holes in the new wheels for crank pins and finish bore with taper or parallel attachment. It will turn old crank pins with the parallel turning attachment, and finish pins with grinding attachment.

Method of operating the machine.

The axle and wheels are lifted by the crane into position and set to correct dead centre of the machine by special centring bars on the heads. The heads are then set to the correct crank throw by spacing blocks, the throw in inches being indicated on the block. The headstock carrying a centre mounted on the grinding head is then traversed forward, the radial

adjustment to the wheel and axle being used to bring the crank pin in line with the centre. The head is moved forward until the centre registers with centre pop in crank pin, the crank then being at true quartered centres. If the crank pin is worn too much for grinding only, a parallel turning attachment is provided which can be easily and quickly fitted to the spindle nose of the machine. When the turning operation is complete, the attachment is taken off and replaced by the grinding attachment.

[621 .454.5 (.45)]

5. — Constant-lubrication valve for superheated steam locomotive cylinders.

Figs. 20 to 22, pp. 634 and 635.

(*Engineering*).

The adoption of superheated steam added certain complications to lubrication problems, especially in the case of locomotives on which the pipes connecting the oil pump with the points to be lubricated may be a good many feet in length, and at the same time exposed to the cooling action of currents of air. In order to prevent trouble from steam getting into the supply pipes and condensing, valves of various kinds have been introduced into these pipes near the delivery points, reliance being placed on a pressure being maintained in the lubricating system sufficiently high to overcome that in the steam chest and cylinders, and prevent oil being fed to these parts. Records of high steam consumption and of rapid wear of piston-rings have suggested, however, that lubrication has not been satisfactory, probably due to obstruction in the valves or pipes, the presence of water, etc.

In order to study these problems, the Sächsische Armaturenfabrik, W. Michalk and Sohn, of Freital-Deuben, near Dresden, fitted glass tubes and pressure gauges at various points in the pipes of the lubricating system and also near the cylinders on locomotives, observations being made with piston valves in good condition and again after they had become worn in service. The diagram reproduced in figure 20, herewith, shows the kind of

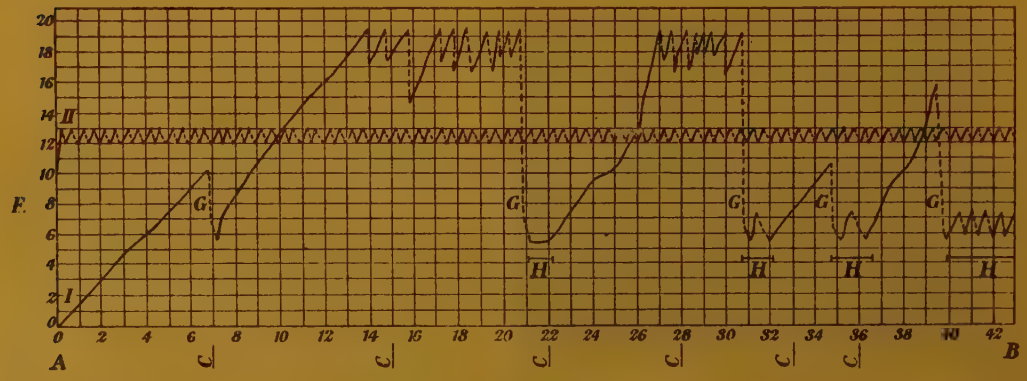

Fig. 20.

record obtained of a typical run on a local service on a line 72 km. (45 miles) in length with numerous stops. The vertical scale indicates pressure in the oil-supply pipe in kilograms per square centimetre. The horizontal scale gives distances in kilometres. Starting from the point A, the oil pressure gradually rises until the first stop is reached at C, and the pump stops working. This results in a drop in pressure G, which is made good on re-starting, the pressure continuing to rise thereafter until something in excess of steam-

chest pressure is realised. At subsequent stops similar falls of pressure are recorded. The parts of the curve marked H indicate stretches on which the regulator was closed either prior to a station stop or drifting. Such operations involve reduction of steam-chest pressure, and therefore are accompanied by a considerable discharge of oil from the supply pipe. The discharge of oil to the steam chests is controlled usually by a valve held up to its seat by steam-chest pressure and a small spring. The oil pump has to raise the pressure in the oil system above the resultant value of these two. For this reason, at the commencement of a trip the locomotive may, indeed, run for some time before oil actually reaches the valves and cylinders. Any use of the regulator which results in a drop of pressure in the steam chest will be accompanied by a considerable discharge of oil. If the valves in the oil system wear, steam and water may find their way into the oil pipes.

In order to make the supply more regular, the firm in question have produced the valve shown in section in figures 21 and 22, for use in the oil-delivery pipe, close to the steam chest.

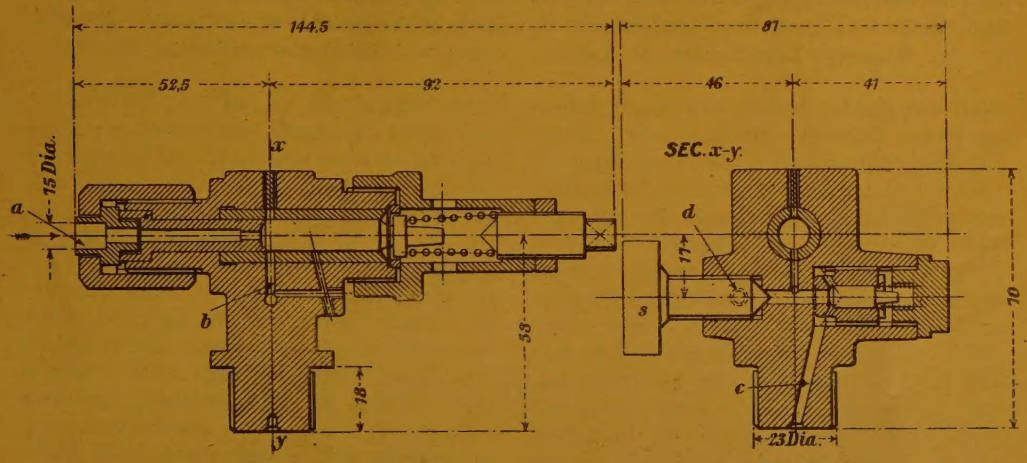

Fig. 21.

Fig. 22.

Oil enters this fitting by the passage *a*. The main part of the valve consists of a piston under the control of a spring only. It will be noticed that when the valve is in the closed position, as in figure 21, the passage *b*, which leads past the check valve, shown in section in figure 22, is overrun by the valve body. Any pressure which may build up in *b* due to leaks in the check valve does not affect the pressure required to move the valve. The pressure controlling this is regulated by the adjustable screwed plug on the right of figure 21, and the amount of compression imposed on the spring. The check valve is very similar in construction to the main valve, oil finally passing to the steam chest by the passage *c*. The thumb-screw cock *s*, figure 22, is a test cock, coupled by means of the passage *d* with a gauge glass. By unscrewing *s* slightly, it is possible to test the correct working of the main valve. The position of this cock between the valve and the point to be lubricated, instead of between the check valve and the oil pump, is characteristic for the new device.

The effect of the use of such a fitting is indicated by curve II in the diagram, figure 20. After building up the requisite pressure to overcome the spring pressure above, the supply of lubricant is regularly maintained with only slight fluctuations, and is seen to be independent of the variable steam chest pressure, whether the engine was running under steam or drifting.

[385. (06.5)]

6. — The third international congress of the Scientific Organisation of Labour.

During the first ten days of the month of September next, the Third International Congress of the Scientific Organisation of Labour will be held in Rome, and subsequently, visits will be made to the most important industrial centres in Italy.

His Excellency, Signor Mussolini, has agreed to be the President of the Honorary Committee. The Presidency of the Congress has been confided to the Italian National Office for the Scientific Organisation of Labour created by the Italian General Industrial Confederation and other Associations.

The object of the Congress will be the discussion of the most important problems that have arisen in the modern development of industry, agriculture, and public services, amongst which may be mentioned, the grouping of industries in large trusts, the exact distribution of space and of time in industrial and agricultural operations, the scientific study of the aptitude of workmen for different crafts, and their better utilisation, etc.

NEW BOOKS AND PUBLICATIONS

[385. (0.91 (.493)]

DE LEENER (GEORGES), Professor at the free University of Brussels. — **Les chemins de fer en Belgique.** — Leur passé. La nouvelle Société Nationale des chemins de fer belges. Ses perspectives d'avenir. — (**Belgian Railways.** — Their History. The New Belgian National Railway Company Their future prospects). — One volume in 8vo (7 1/2 × 5 1/8 inches) of 249 pages. — 1927, Brussels, Maurice Lamertin, Publisher, 58-60, rue Coudenberg. — Price : 20 francs, Belgian currency.

The legal position of the Belgian railways was completely altered in 1926. The working of the State system was handed over for a period of 75 years to a Company entitled « the Belgian National Railway Company ».

The change was followed with much interest both at home and abroad, at home because of the circumstances in which it was made, and abroad because it was a new solution of the frequently discussed question of State versus Company operations.

Mr. De Leener has in his studies on economic questions given much attention to transportation, and was consequently well qualified to describe and comment upon this important event, marking as it does a new era in the operation of the Belgian lines.

He has taken care to elucidate the subject for those who wish to understand the task accomplished by the Government and approved by Parliament.

He has commenced his book by tracing the growth of the present system from the early days when the lines were built by the State, through the period when the lines were conceded to private companies, up to the repurchase by the State.

After shewing the economical and social conditions under which the lines work, the author recalls previous attempts to remove the working of the railways from State control.

In the 4th chapter, the creation of the National Company is described. The reader will therein see that its organisation results from two ideas : to improve the state of the public finances, and to industrialise the railways.

A study of the legal position of the Company, and a consideration of the rights of the staff, which rightly was one of the main preoccupations of the legislators, follow.

The questions : What results will the Company give? Are its facilities such as will enable it to attain the desired end of an economical and profitable operation of the system? are discussed in the two chapters headed : *The operating conditions of the National Railway Company* and *the tariff question.* In the latter he emphasises the low cost which was the good feature of the Belgian rates, and whilst admitting that the principle of making traffic bear the rates they can carry, he advances the theory that further improvements can be made in this direction.

In the last chapter of the book the author expresses the opinion that the

system is able to give the expected financial results.

During his investigation, he recognises the many advantages of the new system, whilst indicating the defects and the remedies that appear to him to be applicable thereto. The constructive nature and impartial criticism of the work are to be commended.

The prosperity of the railways is more than ever closely bound up with that of the country. Everyone, whether on the railways or not, who wishes to form a sound opinion on this matter is under a debt of gratitude to Mr. De Leener for having written so well informed and instructive a book.

As an appendix, the reader will find the text of the laws, royal decrees and Government regulations relating to the new Company.

E. M.